BACKGROUND REPORT TO

RD&D-PROGRAMME 92

Handling and final disposal of nuclear waste

Siting of a deep repository

September 1992

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FOREWORD

The Act on Nuclear Activities (SFS 1984:3) prescribes in Section 12 that a programme shall be prepared for comprehensive research and development and other measures that are required to safely handle and finally dispose of the radioactive waste from the nuclear power plants. The responsibility lies primarily with the owners of the nuclear power plants. These owners have commissioned SKB to prepare the prescribed programme. According to Section 25 of the Ordinance on Nuclear Activities (SFS 1984:14), this programme shall be submitted for review in the month of September every third year.

The purpose of this third programme is to fulfill the above obligations.

The programme is presented in a main report and in three background reports. The programme is called RD&D Programme 92 where RD&D stands for Research, Development and Demonstration. The reason for the change of name compared to previous R&D programmes is to underscore the fact that, starting with the work at the Äspö Hard Rock Laboratory and the plans presented in this programme, the emphasis of the programme has been shifted towards demonstrating different parts of the selected disposal system. The main report describes the programme in its entirety. This background report provides a more detailed account of ongoing and planned work for siting a deep geological repository. The other background reports deal with the Äspö Hard Rock Laboratory and R&D work during 1993–1998.

This background report is intended to present a complete account of the background to and plans for the siting of a deep repository. The report has been written so that the reader can read it on its own without first having read the main report of RD&D Programme 92. All text relating to siting which is found in the main report (in particular Chapter 9) is also contained in this background report, which, in addition, presents a more complete background and further details.

Stockholm, September 1992

SWEDISH NUCLEAR FUEL
AND WASTE MANAGEMENT COMPANY

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SUMMARY

The siting of the facilities for the disposal of spent nuclear fuel and other long-lived nuclear waste is one of the central remaining tasks within the Swedish waste programme. Work relating to the siting of the repository is being conducted in stages and will continue for most of the 1990:ies. This report describes the background to, the goals for and structure of SKB's activities relating to the siting of a deep geological repository. The report describes the situation and plans at a relatively early stage of the siting process.

SKB's work on the siting of a deep geological repository is based on the requirement in the Act on Nuclear Activities that nuclear power plant licence-holders shall "safely handle and finally dispose of nuclear waste arising in the activity". This requirement means that it is the obligation of the nuclear industry to work to achieve the safe final disposal of all nuclear waste. An important part of SKB's work on siting is, thus, to focus all work relating to the disposal of nuclear waste on developing concrete applications of the design concepts for deep geological disposal which have been developed in the comprehensive RD&D programme. The knowledge required to achieve such a disposal of nuclear waste and to assess the long-term safety exists today.

Another equally important part of SKB's work is to, as far as possible, ensure freedom of choice in the future and to not unnecessarily exclude other alternative solutions by reaching what may appear to be final decisions on the repository system and site already in the 1990s. Thus, SKB plans to accomplish its research and development work by selecting a suitable site and constructing a deep repository for demonstration deposition (with a capacity for about 10% of the entire quantity of waste). When demonstration deposition has been completed, the experience gained will be evaluated before a decision is made to expand the facility to full-scale capacity. This plan also allows for the retrieval of the deposited waste for alternative handling. This means that it must be possible to retrieve the deposited spent nuclear fuel during the period of demonstration deposition. The siting process is only affected to a limited extent by whether a deep repository for demonstration deposition or a full-scale deep repository is planned.

For the encapsulation of spent nuclear fuel, SKB plans to expand the central interim storage facility for spent nuclear fuel (CLAB) at the Oskarshamn Nuclear Power Station. The spent fuel is already being stored at CLAB, and SKB believes that the expansion of CLAB with an encapsulation plant for spent nuclear fuel has clear advantages in terms of logistics, resource utilization and environmental impact. If special reasons emerge during the course of the work in favour of encapsulating the fuel at the deep repository instead, SKB will, of course, also consider the question of alternative siting of the encapsulation plant.

Siting and construction of a deep repository is planned to take place in stages during the 1990s and a few years into the 21st century. According to the estimates that can be made at this stage of the time required to take decisions, carry out necessary studies and investigations and obtain necessary permits, demonstration deposition could be started in about 15 years at the earliest.

The SKB 91 safety assessment, which SKB carried out during 1989–1992, shows that the requirements on the properties of the bedrock are limited. "...SKB 91 shows that a

repository constructed deep down in Swedish crystalline basement rock with engineered barriers possessing long-term stability fulfills the safety requirements proposed by the authorities with ample margin. The safety of such a repository is only slightly dependent on the ability of the surrounding rock to retard and sorb leaking radioactive materials. The primary function of the rock is to provide stable mechanical and chemical conditions over a long period of time so that the long-term performance of the engineered barriers is not jeopardized". The studies and investigations that have been conducted of the bedrock in Sweden during the past 15-year period show that these properties exist at many places and that there are, as a result, many sites possessing the necessary geological and technical prerequisites for constructing a safe repository.

Present-day knowledge is sufficient for selecting a preferred system design, for designating candidate sites for siting a repository, for characterizing these sites and for adapting the repository to local conditions.

The selection of candidate sites for the deep repository will be based on the fundamental requirements that must be made on a deep repository site from safety-related, technical, societal and legal viewpoints. With the help of a safety assessment, it must be demonstrated for the selected site and selected repository system that the safety requirements imposed by the authorities are met. It must be possible to build the repository and carry out deposition in the intended manner. The siting process, the investigations and the construction work shall be carried out so that all relevant legal and planning-related requirements are met. And last, but not least, it shall be possible to carry out the project in harmony with the municipality and the local population.

An important point of departure for the planning of the siting process is the Government's decision regarding R&D Programme 89 /1-1/. It states the following: "The

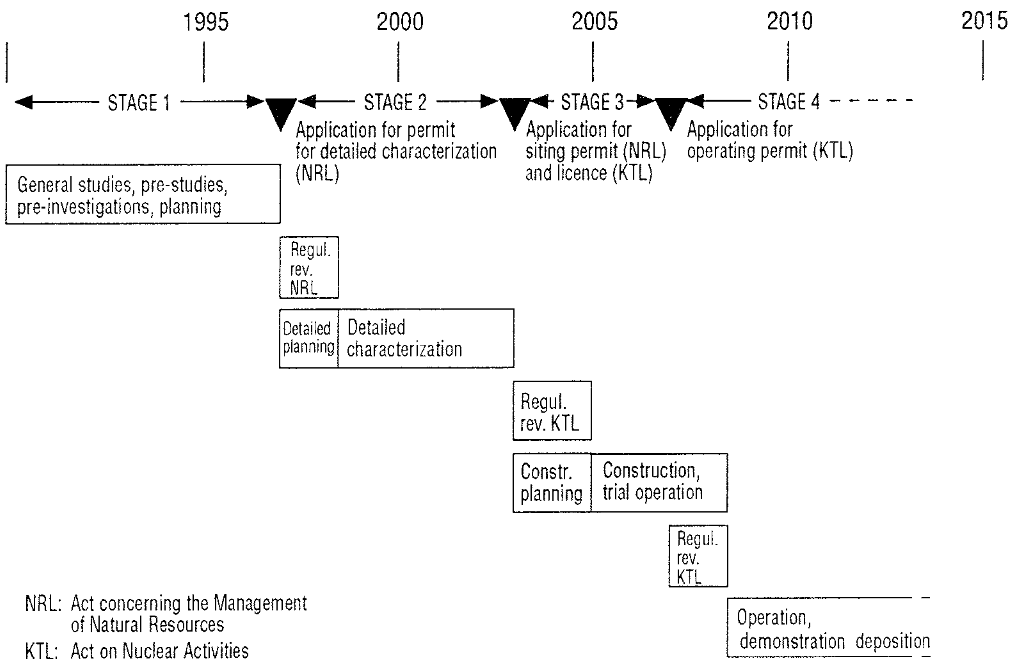


Figure 1 *Overall schedule for the siting and construction of a deep repository for demonstration deposition.*

Government notes that SKB's choice of sites for a final repository will be reviewed by different authorities in connection with SKB's application for permission to carry out detailed characterization of two such sites under the Act (1987:12) concerning the Management of Natural Resources etc., the Environment Protection Act (1969:387) and the Planning and Building Act (1987:383)." Furthermore, the Government emphasized that SKB should, during the course of the siting work, furnish information to the national authorities, county administrative boards and municipalities concerned.

Based on these guidelines, the work of siting and construction of the deep repository is planned to proceed in the following stages, see Figure 1.

Stage 1: General studies. Analysis of siting factors. Possible feasibility studies of presumptive candidate sites. Selection of candidate sites. Pre-investigations at a couple of sites, including preliminary design. Technical and socio-economic studies. Evaluation of the results. NRL application for detailed characterization including an environmental impact statement (MKB) with an initial safety assessment.

Stage 2: Detailed characterization including excavation of necessary shafts and tunnels to planned repository depth. Evaluation of the results. Safety report. Environmental impact statement (MKB). Detailed design. Application for siting permit and licence (NRL, KTL).

Stage 3: Construction and installation of equipment for handling/deposition. Final safety report. Application for operating permit (KTL).

Stage 4: Commissioning. Demonstration deposition.

1 STRUCTURE OF THE REPORT

The first chapters ("Background and Goals", "Construction in Stages – Demonstration Deposition" and "General Premises") aim at providing an introduction and background to the RD&D programme, particularly the planned work relating to siting.

Chapter 5 "Facilities and Siting Alternatives" summarizes the systems and facilities included in the programme for demonstration deposition of nuclear waste. The aim of the chapter is to present the reader with a concrete picture of the facilities for which a suitable site must be found and which must be constructed. The chapter also aims at showing the flexibility involved with regard to the location (siting) of the various facilities (encapsulation plant, transportation system and loading terminals, as well as deep repository with surface and underground facilities). A more detailed technical description of the facilities can be obtained from the report "Project on Alternative Studies for Final Disposal (PASS). Final Report."

Chapter 6, "Siting Process and Schedule" is an overall description of the entire siting process, from the general studies currently in progress to the ultimate goal where a permit to start demonstration deposition has been obtained. The aim of this description is to provide the reader with an overall picture of the main characteristics of all the work relating to siting which has been planned.

The following chapters provide more detailed accounts of:

- the points of departure for the site selection process and important siting factors (Chapter 7),
- previous experience of site investigations and siting issues (Chapters 8 and 9),
- the structure and plan for work to be carried out during 1993-98 (Chapters 10 to 13).

The aim of these chapters is to provide a detailed account of the plans for the next 6-year period, as stipulated in the Act on Nuclear Activities.

This report is one of the background reports in the 1992 program for Research, Development and Demonstration (RD&D Programme 92). RD&D Programme 92 consists of a main report which summarizes the entire programme and three background reports which contain a more detailed account than the main report of work carried out so far and of the plans for future work within central parts of the programme.

The three background reports are:

- Background Report to RD&D Programme 92
  Treatment and Final Disposal of Nuclear Waste
  Siting of a Deep Geological Repository
- Background Report to RD&D Programme 92
  Treatment and Final Disposal of Nuclear Waste
  Detailed R&D Programme 1993–1988
- Background Report to RD&D Programme 92
  Treatment and Final Disposal of Nuclear Waste
  Äspö Hard Rock Laboratory

An important basis of the strategy and plans reported in RD&D Programme 92 is the three final reports on the results of major projects completed during the past 3-year period, namely:

- SKB 91
  Final Disposal of Spent Nuclear Fuel
  Importance of the bedrock for safety
- The Stripa Project
  Summary of Results (1980-1992)
- Project on Alternative Studies for Final Disposal (PASS). Final Report.

2 BACKGROUND AND GOALS

SKB's central task and the overall goal of SKB's activities is the safe disposal of all Swedish nuclear waste. The Act on Nuclear Activities, Section 10 stipulates the legal requirements in this area:

"The holder of a licence for nuclear activities shall ensure that the necessary measures are taken in order to:

1 maintain safety, with due consideration to the nature of the activity and the conditions under which it is carried out;

2 safely handle and *finally dispose of* nuclear waste or non-recycled nuclear material arising in the activity; and

3 decommission and dismantle in a safe manner plants in which the activity is no longer to be carried out."

The requirement on final disposal (see text in italics above) means that it is the obligation of the nuclear industry and, thereby, SKB, to develop, site and construct a deep repository for spent nuclear fuel and other nuclear waste, e g from reactor decommissioning. This means that even if CLAB, at present and for several decades in the future, represents a safe system for monitored storage of spent fuel, the development and implementation by the nuclear industry of a system for final disposal of waste is required by law. The legal requirement cannot, other than for a limited period of time, be met by a storage system which must be monitored or maintained in some way to ensure its safe performance. This is also stipulated in the criteria now being formulated by the Nordic radiation protection authorities /2-1/, which specify the following:

Principle 2: Burden on future generations

The burden on future generations shall be limited by implementing, at an appropriate time, a safe disposal option which does not rely on long-term institutional controls or remedial actions as a necessary safety factor.

This requirement has also been formulated at an international level /2-2/ and has been generally accepted as a fundamental principle by all countries producing nuclear power.

Since additional facilities for the treatment and storage of waste are required for the ultimate fulfillment of all the legal requirements, SKB is channelling all work into the realization of such facilities. In SKB's view, it is now time to start to take the step from research and development to application.

The goal of SKB's work on siting is that the necessary facilities, see Section 7.1 of the main report and Chapter 5 of this background report, should be sited and constructed in accordance with all the relevant legislation and regulations, and in harmony with the municipalities and local population concerned.

SKB is closely following the debate on nuclear waste. In SKB's view, the broad spectrum of political and public opinion should be able to reach a consensus on the following fundamental principles for nuclear waste management in Sweden:

- Nuclear waste already exists. This must be disposed of in a safe manner in our own country.
- The waste disposal issue shall, in all essentials, be solved by the generation which is using the electricity produced by the nuclear power plants.
- At the same time that work focusses on the concrete implementation of a final disposal method for all spent nuclear fuel and other long-lived waste, there is reason to maintain freedom of choice, as far as possible. This is important in view of alternative methods and any improved or simpler solutions that may come to light or due to a re-evaluation of current decisions regarding recovery (reprocessing) of some of the fissile elements (U, Pu) in the fuel.

The views which have been put forward, especially on the value of maintaining freedom of choice as long as this is not detrimental to safety or does not unnecessarily delay the solution of the waste issue, have contributed to the fact that SKB now plans to complete R&D work in the area of nuclear waste by siting and constructing a deep repository for demonstration deposition of spent nuclear fuel, with the possibility of retrieving the encapsulated fuel. The motives for this strategy are presented in greater detail in the following chapter.

3 CONSTRUCTION IN STAGES - DEMONSTRATION DEPOSITION

SKB's previous plan of work and schedule for siting and building a repository for spent nuclear fuel entailed that after pre-investigations at three sites and detailed characterization at two during the 1990s, a decision would be taken a few years into the 21st century to build a repository at one of the sites. During the circulation of R&D Programme 89 for comment and review, a proposal from the National Board for Spent Nuclear Fuel (SKN) was discussed to the effect that a demonstration-scale repository should first be built, for example 5–10% of the full-scale repository /3-1/. In its decision concerning R&D Programme 89, the Government asserted "... that one of the premises for further research and development activities should be that a final repository for nuclear waste and spent nuclear fuel shall be able to be put into operation gradually with evaluation at interim stages and opportunities for adjustments. In the next R&D Programme, under the Act on Nuclear Activities, SKB should explore the possibilities of including a demonstration-scale final repository as a step in the work of designing a final repository" /3-2/.

In the planning of the present RD&D programme, SKB considered the possibility of building and commissioning the repository in stages. The result is that SKB finds that a demonstration phase has considerable advantages. The present programme thereby calls for completion of the research, development and demonstration work by first building the final repository as a deep repository for demonstration deposition of spent nuclear fuel. When the demonstration deposition has been completed, the results will be evaluated before a decision is made whether or not to expand the facility to accommodate all the waste. This plan also makes it possible to consider whether the deposited waste should be retrieved for alternative treatment. The latter option means that it must be possible to retrieve deposited fuel during the period the facility is being operated for demonstration purposes. The siting process is only affected to a limited extent by whether the planning applies to a deep repository for demonstration deposition or to a complete deep repository. The requirements on background information from SKB in the different phases (pre-investigation, detailed investigation, construction of repository) are essentially the same.

The most important reason for SKB's plan to build a repository for demonstration deposition is that this makes it possible to demonstrate the following, without the necessity of making what are sometimes described and perceived as definite decisions:

- the siting process with all its technical, administrative and political decisions,
- the process and the methods for step-by-step investigation and characterization of the deep repository site,
- system design and construction,
- full-scale encapsulation of spent nuclear fuel
- the handling chain of spent nuclear fuel from CLAB to deposition in the repository,
- the operation of a deep repository,

- the licensing of handling, encapsulation and deep disposal, including the assessment of long-term safety,
- (retrievability of the waste packages).

Beyond this, it is also possible to study the condition of the barriers a given shorter or longer time after deposition. However, the impact of the surrounding environment on the barriers is a factor which should primarily be investigated using non-radioactive material in the Äspö Hard Rock Laboratory.

The long-term safety of the deep repository cannot be demonstrated through field tests. Permission to proceed with the construction of a deep repository must always be based on a technical-scientific assessment of the performance of the repository over a long period of time. However, the background information that is gathered in conjunction with the construction of the deep repository for demonstration deposition allows a safety assessment to be performed based on site-specific "full-scale" data.

The reason SKB is planning a demonstration deposition is not doubts as to the feasibility and safety of the deep disposal scheme. The plan should be viewed as an expression of an awareness of and respect for the fact that the solution of the nuclear waste problem arrived at by the R&D work needs to be concretely demonstrated to the people in society who are involved and who are far beyond the circle of experts, in order to gradually build up their confidence. It is SKB's opinion that a demonstration deposition of spent nuclear fuel with full freedom of choice for the future is a good way of enlisting broad support for the method of disposing of the nuclear waste.

The planning of the deep repository for demonstration deposition also means that the present-day generation is deciding for a span of time that roughly corresponds to its own active lifetime, leaving it up to the next generation to make its own decision with as much background information as possible. This division of responsibilities and freedom of choice between our own and the future generation can be described as follows:

1. It is the responsibility of the present generation (users of nuclear power and producers of nuclear waste at an active age between 1970-2010) to:
   - develop a safe deep geological repository system,
   - site a deep geological repository,
   - construct a deep geological repository which allows for the retrieval of the encapsulated waste, and which satisfies the requirements on long-term safety,
   - set aside sufficient funds to cover the future costs of the entire system.
2. It is the responsibility and freedom of the next generation (those who are at an active age in the year 2010 and after) to
   - conduct a new, independent assessment of the final repository's long-term safety,
   - evaluate alternative methods,
   - decide to either

     complete the disposal of waste according to the current method and seal the repository or

     retrieve the waste and dispose of it by an alternative method.

The work up until all nuclear and other long-lived waste in Sweden has been deposited in a sealed deep repository is therefore planned to be carried out in two main phases: demonstration deposition and final disposal. In all, the work extends over a period of more than 60 years. The decision to take the step to final disposal will not be taken until after demonstration deposition has been completed, the results evaluated and other alternatives considered. These decisions lie beyond the year 2010. The plans that are discussed in this programme have to do with the activities that are

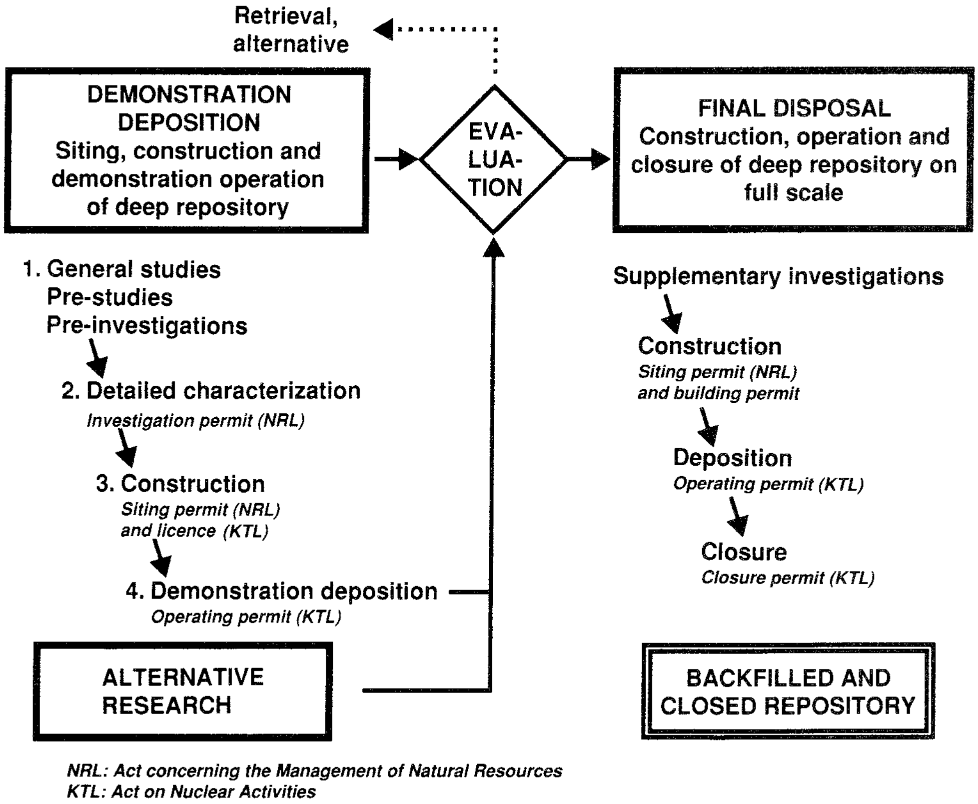


Figure 3-1 *Program for demonstration deposition and final disposal with evaluation at an intermediate stage. The siting and construction process follows the licensing process also shown here.*

required to site and construct the facilities that are needed for demonstration deposition. It is SKB's judgement that the deep repository will later be expanded to full scale. However, it is not meaningful to discuss, at this point in time, the details of how this will be done. The important task for now is to demonstrate a possible method for long-term safe disposal and to provide future engineers and decision-makers with the best possible background information for their decisions.

Figure 3-1 is a schedule of the entire process as SKB expects it to be. Both of the main phases are shown as well as the evaluation to be carried out at an interim stage and the stage-by-stage siting, licensing and construction work in each phase. The following chapter presents the plans for the first phase, i e siting and construction of a deep geological repository for demonstration deposition.

4 GENERAL PREMISES

The fundamental goal of the safe final disposal of nuclear waste generated in the operation of the nuclear power plants can in principle – as was demonstrated in the KBS-3 report – be achieved by building an underground rock facility in which encapsulated fuel is emplaced in a specified manner. The combination of engineered (the low-soluble fuel, the canister, the bentonite buffer) and natural (the rock) barriers effectively isolates the waste for a sufficiently long period of time. In other words, safety rests on a natural-scientific and technological basis. However, in order to achieve the level of safety sought after, the system of engineered barriers must be achieved in reality, i.e. the necessary facilities must be sited, built, operated and finally closed and sealed. The realization that this is as much a legal and a societal process as it is a technical one must guide the siting work.

Figure 4-1 is a schematic illustration of the goals, premises and possibilities for the siting work. An analysis of the premises provides an idea of what requirements must be met and what flexibility exists in the means of achieving the goals, as well as under what circumstances there is a risk of being blocked.

A deep repository can be regarded as a medium-sized industrial facility on the surface, plus an underground part with relatively small but deep-lying rock caverns. Well-established rules apply to every industrial siting. Just like any other industrial facility, the deep repository will be judged according to these rules. But a deep repository is also a nuclear installation, and the question of how the nuclear waste is to be disposed of is given special attention. Because of this, combined with the ambition to carefully

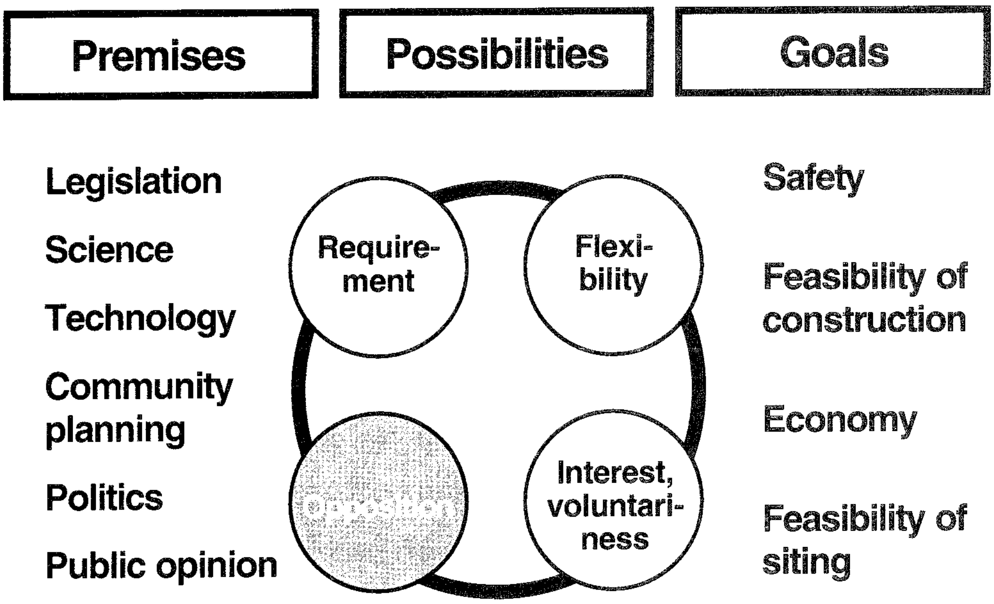


Figure 4-1 *Schematic illustration of goals, premises and possibilities*

study all aspects of repository function and meet stringent safety requirements, the siting process for a deep repository is extra comprehensive and thorough.

The premises within the subject areas indicated in Figure 4-1 are being analyzed in the ongoing siting work. Since siting is a long process, it is possible that some premises will change during the course of the process.

4.1 LEGAL PREMISES

Sweden was early to enact laws governing safety, division of responsibilities and financing forms within the field of nuclear waste management. This has contributed to the fact that there is now a functioning structure and a clear division of roles within the research and development work to guide the siting and construction of the remaining facilities. The premises in this respect must, therefore, be considered to be good. SKB has compiled a summary of the laws and ordinances that will, or may be applicable at some point in the siting process /4-1/. This summary reveals that:

- The Act concerning the Management of Natural Resources (NRL) and the Act on Nuclear Activities (KTL), are the two central laws under which the Government must grant permission.
- Certain other laws or regulations will or may be applicable at some point in the process.
- An environmental impact statement (MKB) should be prepared at an early stage of the siting process and then be updated and particularized as the work progresses. The MKB shall provide an overall assessment of the planned activity's "impact on the environment, health and management of natural resources." The MKB constitutes a supporting document in the licensing process. It will also serve as a tool for informing all concerned parties and giving them an opportunity to offer viewpoints on what issues are important to take up in connection with the various licensing processes.
- The siting process will require an effective interaction between authorities concerned, the Government, relevant municipalities, county administrative boards and SKB.

4.2 SCIENTIFIC AND TECHNICAL PREMISES

Research on the handling and final disposal of nuclear waste got under way in earnest in Sweden in the mid-1970s. SKB and others have conducted comprehensive and targeted research and development work. Geology, materials, chemistry and other aspects have been studied in detail. Three integrated safety assessments, two by SKB (KBS-3 /4-2/, SKB 91 /4-3/) and one by SKI (Project -90 /4-4/) have been conducted in Sweden. These safety assessments all indicate that there are good scientific and technical premises in Sweden for the construction of a deep disposal system which meets high safety requirements. Similar safety assessments have been conducted in other countries /4-5, 6, 7/ and internationally /4-8/ with similar conclusions regarding feasibility and safety.

The OECD/NEA's and IAEA's radioactive waste management committees, where the safety authorities of all the major nuclear power producing nations are represented, have, after in-depth discussion, stated that: "safety assessment methods are available today to evaluate adequately the potential long-term radiological impacts of a carefully designed radioactive waste disposal system on humans and the environment. Appropriate use of safety assessment methods, coupled with sufficient information from proposed disposal sites, can provide the technical basis to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations" /4-9/.

With the above background and based on its own experience from 15 years of R&D activities, whose current status is described in other sections of RD&D Programme 92, SKB draws the following conclusions:

- The scientific and technical premises that are necessary for implementing a safe final disposal of the spent nuclear fuel exist in Sweden.
- The Swedish crystalline basement offers good geological conditions for a deep repository, and it is, therefore, possible to find sites that meet the stipulated requirements in most parts of the country.
- The best way to proceed in realizing the deep repository system and to acquire knowledge of its safe performance that is as reliable as possible is to select, investigate and evaluate specific candidate sites.

4.3 SOCIETAL PREMISES

The siting of facilities in a system for deep geological deposition of spent nuclear fuel must be accomplished in harmony with the premises and plans that exist in society. The investigations and the facilities will require land space, create jobs and have spin-off effects for local industry and services. Furthermore, they can have an impact on the environment visually and in the form of transportation, drilling, rock blasting and construction activities. All of these aspects must be described and discussed with the municipality, the citizens concerned and the authorities. The facilities which have been planned are described in Chapter 5. From the description, it is clear that there is a certain scope for adapting the siting as well as the detailed layout of the facilities at a selected site so as to limit, as much as possible, any disturbing impact the facilities may have. The possible societal impact of the siting of a deep repository is discussed in further detail in Chapter 11. Societal factors which can affect the selection of a suitable site are discussed in Chapter 7.

In summary, it is SKB's judgement that

- the societal premises are important to both site selection and detailed emplacement and configuration of the facilities on the selected site,
- it is possible to satisfy social, planning and environmental requirements,
- the investigation activities and the deep repository facilities can bring substantial benefits to a locality. They represent the application of advanced environmental and geotechnical engineering, create employment opportunities, fulfill high requirements on safety and will attract considerable scientific and international interest.

4.4 POLITICAL PREMISES AND PREMISES RELATING TO PUBLIC OPINION

The siting and construction of a deep repository for spent nuclear fuel is a sensitive political and public opinion issue. Experience from both Sweden and other countries show that strong feelings and opinions can be aroused. Opposition to the siting of industrial facilities of all kinds is not unusual in today's democratic society, where many opposing interests, desires and values must be reconciled. On the other hand, there is no reason to overdramatize the potential opposition to a deep repository.

It is SKB's conclusion that

- it is important to have open information channels to and good relations with the municipalities concerned and the citizens who are directly affected by or feel strongly about the siting. This is a necessary prerequisite for success in carrying out the important environmental protection work entailed by deep disposal of the spent nuclear fuel.

5 FACILITIES AND SITING ALTERNATIVES

The facilities which are necessary to achieve the safe deep disposal of spent nuclear fuel are outlined in this chapter. The aim of this chapter is to explain what the whole system involves in practice and to present the existing siting alternatives. In addition, the extent to which the facilities can be adapted to local conditions or demands is discussed.

5.1 FACILITIES

The remaining facilities which are needed in order to treat, handle and finally dispose of all Swedish nuclear waste are described in the main report, RD&D Programme 92 (Chapter 6). Demonstration deposition of spent nuclear fuel requires the following facilities:

A: An encapsulation plant for spent nuclear fuel and an interim storage facility for sealed canisters.

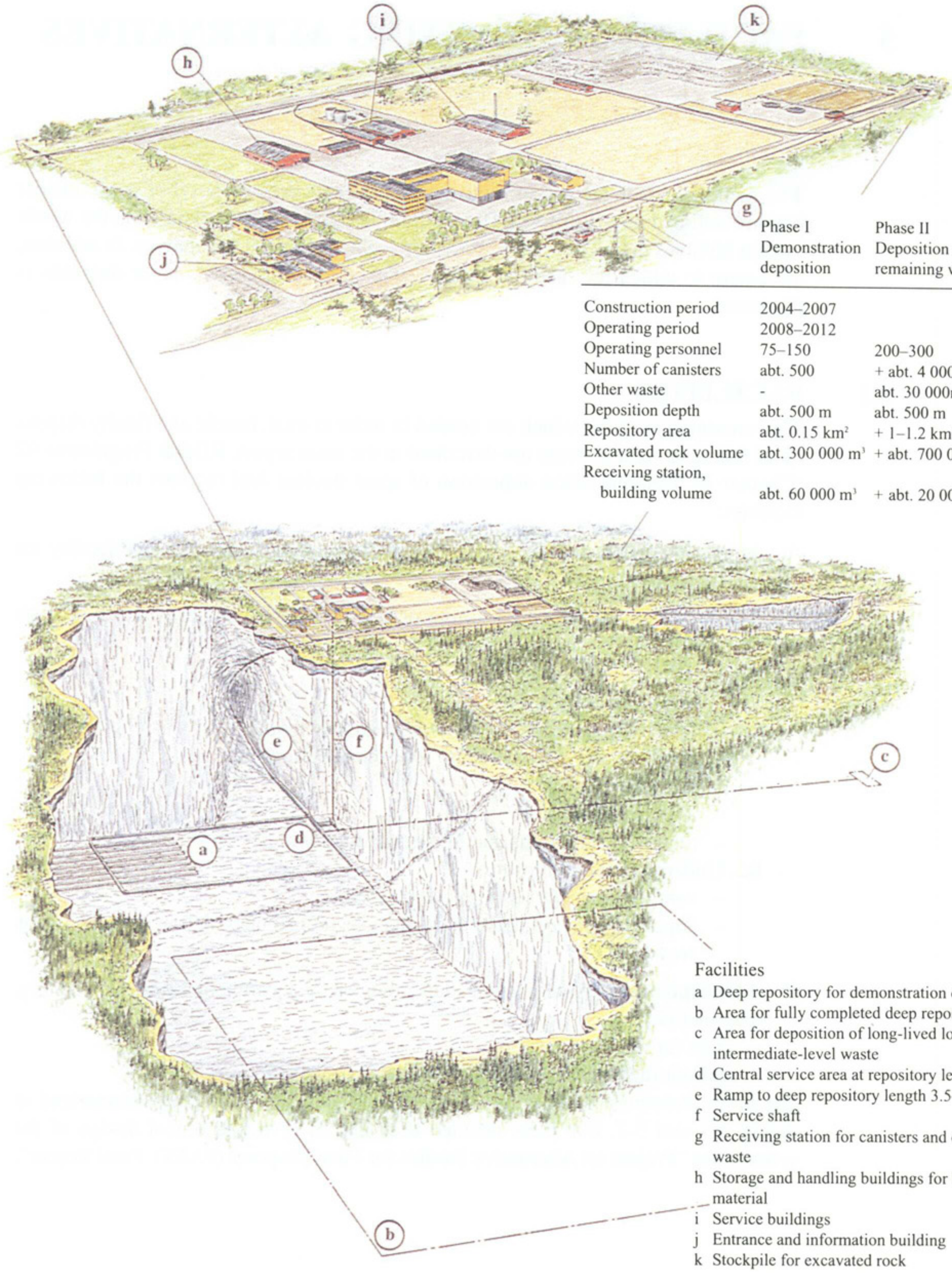
B: A deep geological repository for the storage of encapsulated fuel, which consists of:

B1. Surface facilities for
- receiving canisters
- handling/storage of buffer and backfill material
- handling and possible dump for excavated rock etc
- technical service
- administration
- tunnel constructions and lift/ventilation buildings

B2. Underground facilities for
- control/service/reception (central area).
- depositing encapsulated spent nuclear fuel (transportation and deposition areas).

C: A **transportation system** which, depending on the location of the deep repository, may include
- ships for marine transport
- harbour facilities for reloading from ship to vehicle or train.

The basic characteristics of subsystems B and C are illustrated and summarized in Figure 5-1 and 5-2. For more detailed descriptions of the technical design of the systems see “Project on Alternative Studies for Final Disposal (PASS). Final Report”.



	Phase I Demonstration deposition	Phase II Deposition of remaining waste
Construction period	2004–2007	
Operating period	2008–2012	
Operating personnel	75–150	200–300
Number of canisters	abt. 500	+ abt. 4 000
Other waste	-	abt. 30 000m^3
Deposition depth	abt. 500 m	abt. 500 m
Repository area	abt. 0.15 km^2	+ 1–1.2 km^2
Excavated rock volume	abt. 300 000 m^3	+ abt. 700 000 m^3
Receiving station, building volume	abt. 60 000 m^3	+ abt. 20 000 m^3

Facilities
a Deep repository for demonstration deposition
b Area for fully completed deep repository
c Area for deposition of long-lived low- and intermediate-level waste
d Central service area at repository level
e Ramp to deep repository length 3.5–4 km
f Service shaft
g Receiving station for canisters and other waste
h Storage and handling buildings for buffer material
i Service buildings
j Entrance and information building
k Stockpile for excavated rock

Figure 5-1 *Possible design of a deep repository. For demonstration deposition, about 10% of a full-scale repository will be constructed as shown in the diagram.*

Figure 5-2 *Spent nuclear fuel is stored for about 40 years in water-filled pools in the central interim storage facility for spent nuclear fuel (CLAB) at Oskarshamn. During this time, the radioactivity decays and the heat generated by the fuel is reduced by 90%, which allows for simpler handling of the fuel during encapsulation and transportation to the deep repository. However, since the level of radioactivity will still be high, the spent fuel will be transported in special containers similar to those currently used for non-encapsulated spent nuclear fuel. If the repository is located inland, a harbour terminal will be constructed for receiving and loading the fuel onto trucks or trains.*

5.2 SITING ALTERNATIVES

For the encapsulation of spent nuclear fuel, SKB plans to expand the central interim storage facility for spent nuclear fuel (CLAB) at the Oskarshamn Nuclear Power Station. The spent nuclear fuel is already being stored at CLAB, and SKB believes that expansion of CLAB with an encapsulation plant for spent nuclear fuel has clear advantages in terms of logistics, resource utilization and environmental impact. If special reasons emerge during the course of the work in favour of encapsulating the fuel at the deep repository instead, SKB will, of course, also consider the question of alternative siting of the encapsulation plant.

From the standpoint of logistics, the deep repository can be sited in several ways which differ, in principle. The main alternatives for siting in this respect are:

- co-siting with CLAB
- coastal siting with independent harbour
- inland siting, see Figure 5-3.

It is not possible to determine which siting alternative is preferable until data based on studies and investigations of specific locations have been collected.

5.3 FLEXIBILITY IN THE ADAPTATION OF THE SITE OF THE DEEP REPOSITORY

The deep repository can be divided into surface and underground facilities. In principle, there is considerable flexibility in the location of these parts in relation to each other and in the detailed layout of the individual parts above and below ground. This should give adequate opportunity to adapt the facilities to the local conditions at a site. For example, the surface facilities do not necessarily have to be located directly above the deep repository. If the conditions on the surface above the final repository are not suitable for an industrial facility, the surface facility can, in many cases, be located several kilometers away and connected to the underground facilities via a tunnel. In addition, certain functions, such as the dump and preparation of bentonite for backfilling, the dump for excavated rock and different kinds of technical services can either be established directly on the repository site, or alternatively, established elsewhere in the region. It may be possible to use already existing industrial and service facilities in the area for certain functions.

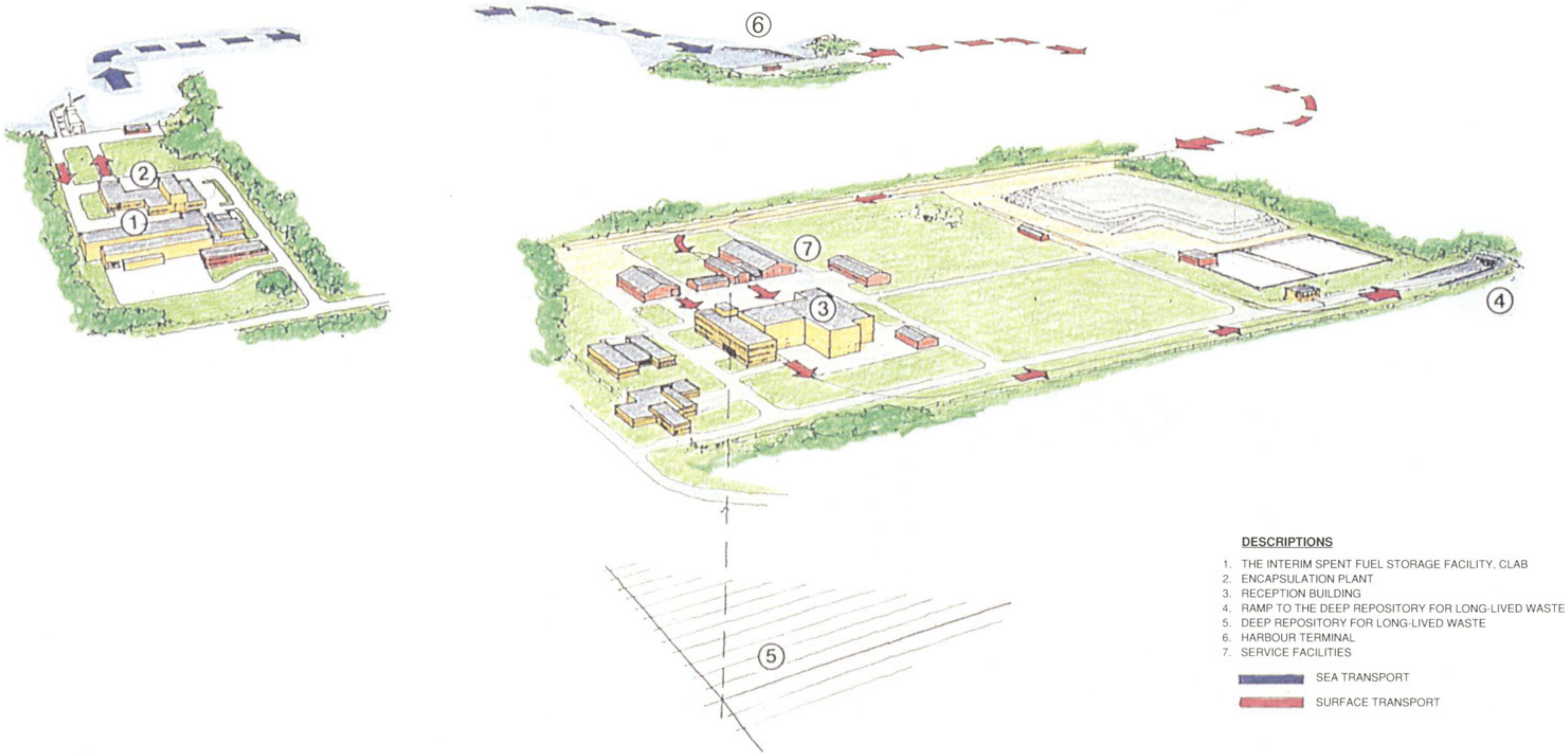


***Figure 5-3** Inland siting of the deep repository. In this case, a reloading terminal is required at the harbour. The fuel is then transported by road or train to the deep repository. The route taken by the encapsulated fuel is indicated in blue (marine transport) and in red (land transport). If the repository is located near the coast, it will not be necessary to forward the fuel by road or train. If the repository is located adjacent to CLAB, marine transport will also be unnecessary.*

6 SITING PROCESS AND SCHEDULE

Siting and construction of a deep repository is planned to take place in stages during the 1990s and a few years into the 21st century. According to the estimates that can be made at this stage of the time required to take decisions, carry out the necessary inquiries and investigations and obtain the necessary permits, demonstration deposition could be started in about 15 years at the earliest. This chapter provides an overall description of what the siting process is expected to involve, including the different stages, schedules and permits required.

6.1 STAGES IN THE SITING PROCESS

An important point of departure for SKB's planning of the siting process is the Government's decision regarding SKB's R&D Programme 89 /6-1/. It states the following: "The Government notes that SKB's choice of sites for a final repository will be reviewed by different authorities in connection with SKB's application for permission to carry out detailed characterization of two such sites under the Act (1987:12) concerning the Management of Natural Resources etc., the Environment Protection Act (1969:387) and the Planning and Building Act (1987:383)." Furthermore, the Government emphasized the fact that SKB should, during the course of the siting work, furnish information to the national authorities, county administrative boards and municipalities concerned.

Based on these guidelines, the work of siting and construction of the deep repository is planned to proceed in the following stages:

Stage 1: General studies. Analysis of siting factors. Possible feasibility studies of presumptive candidate sites. Selection of candidate sites. Pre-investigations at a couple of sites, including preliminary design. Technical and socio-economic studies. Evaluation of the results. NRL application for detailed characterization including an environmental impact statement (MKB) with an initial safety assessment.

Stage 2: Detailed characterization including excavation of necessary shafts and tunnels to planned repository depth. Evaluation of the results. Safety report. Environmental impact statement (MKB). Detailed design. Application for siting permit and licence (NRL, KTL).

Stage 3: Construction and installation of equipment for handling/deposition. Final safety report. Application for operating permit (KTL).

Stage 4: Commissioning. Demonstration deposition.

Development work and preparations for obtaining the permits required for the encapsulation plant will be carried out in parallel to the above. In addition, during the entire process, SKB will conduct supporting research and development work as well as investigations into a transportation system and a system for retrieving deposited canisters. Method development and testing of handling and disposal methods will be carried out at the Äspö Hard Rock Laboratory using inactive materials.

Figure 6-1 is a schematic illustration of the entire programme for demonstration deposition. The content of the various sub-programmes (supporting research and development, Äspö Hard Rock Laboratory etc) is described in the main report and in the other background reports).

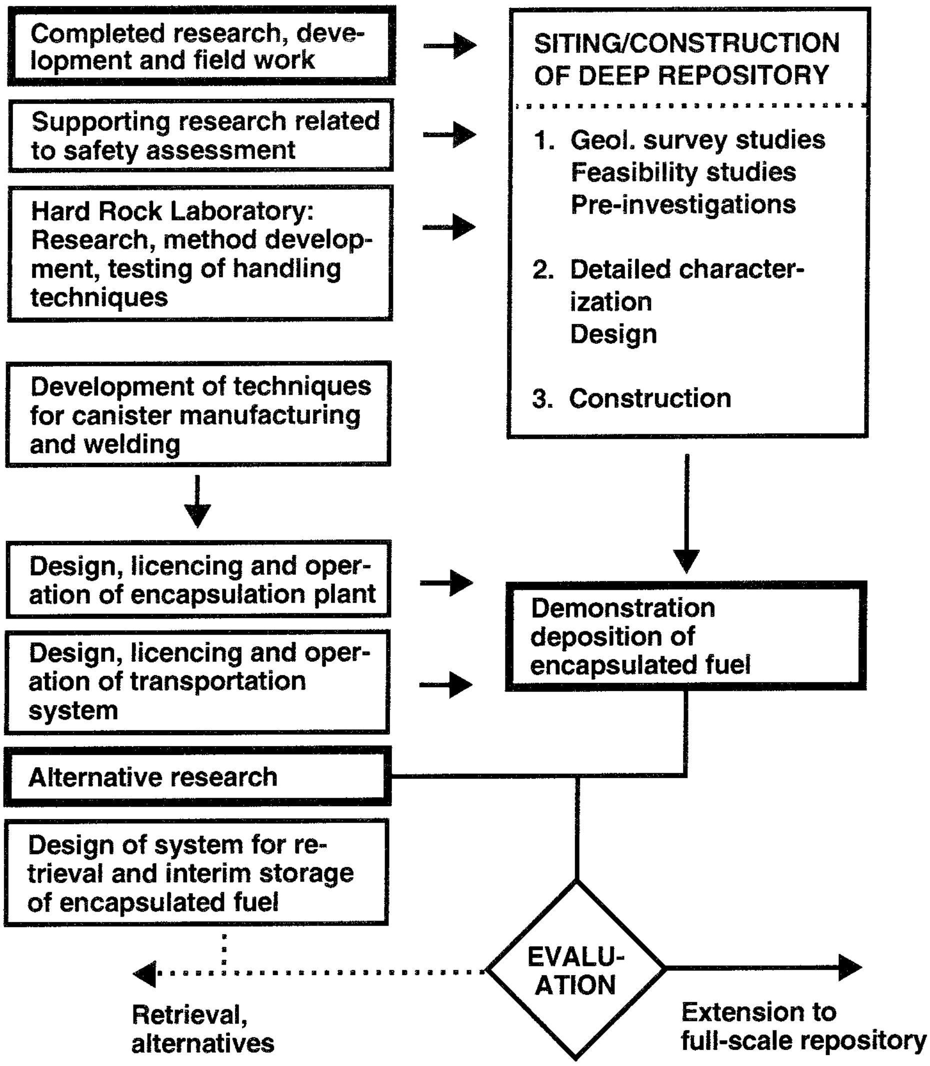


Figure 6-1 *Programme for demonstration deposition showing supporting research as well as development, design and construction work.*

6.2 SCHEDULES

A schedule for the siting and construction of the deep geological repository for demonstration deposition is shown in Figure 6-2. The schedule is based on certain assumptions and assessments of the speed with which it is possible to gather the background data needed for the permit applications. The most important prerequisites are as follows:

- Extensive pre-investigations will be conducted at two candidate areas to obtain the necessary data for the application to carry out detailed characterizations, in accordance with the Act concerning the Management of Natural Resources, etc.,
- Full-scale detailed characterization will be carried out on one site. Only if the site chosen for detailed characterization should prove to be unsuitable should detailed characterization be started at another site.

It should be noted that it takes about 10 years to obtain the necessary data from pre-investigations and detailed characterizations to submit a final siting application in accordance with the Act concerning the Management of Natural Resources, etc. and an application for a licence in accordance with the Act on Nuclear Activities.

The construction of the final repository for the first step of demonstration deposition is expected to proceed very quickly since a considerable part of the rock excavation will be carried out in connection with the detailed characterizations. This means that it will be possible to start depositing canisters some 15 years after the selection of candidate sites.

Detailed schedules will be drawn up at each current stage for work to be accomplished in the subsequent stage. In this way, constant consideration can be given to experience obtained in the course of work and to site-specific conditions which can affect the time needed in reality to carry out the work and obtain the permits. A preliminary schedule of work during 1993–98 is presented in Figure 6-3.

6.3 STAGE 1. GENERAL STUDIES, FEASIBILITY STUDIES AND PRE-INVESTIGATIONS

At this stage, a broad review of the premises for siting of a deep repository will be made, initially. Important siting factors will be identified and analyzed.

A truly clear picture of premises and conditions will not be obtained until concrete area- and site-specific investigations are carried out. Feasibility studies will, therefore, be carried out for those municipalities which, for example, through their own initiatives, display an interest in having a closer examination made of the premises for a deep repository. In a feasibility study, fundamental facts are gathered and evaluated

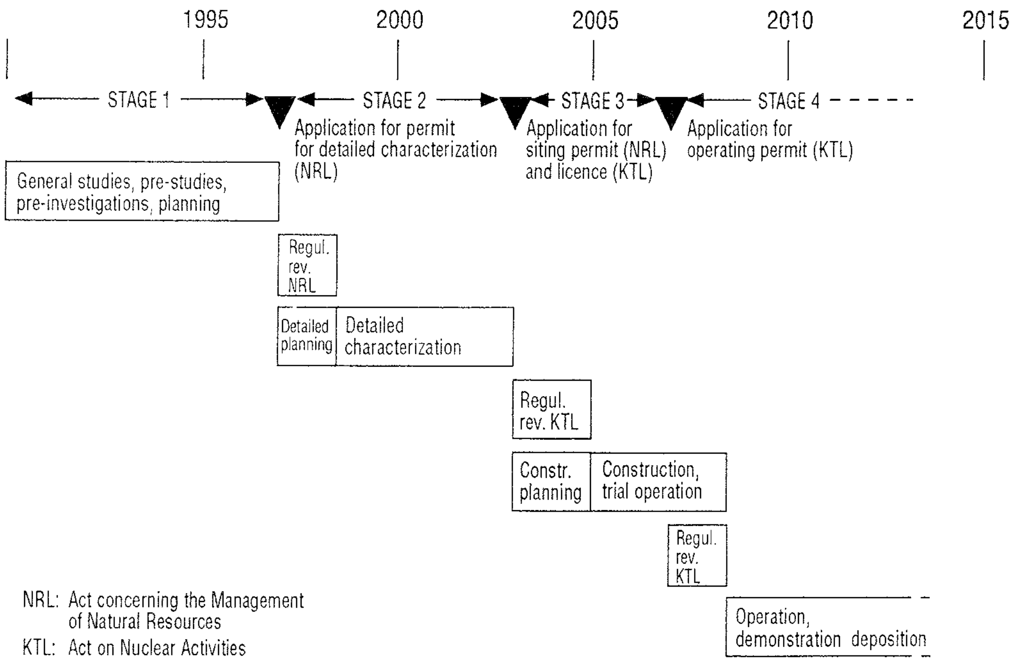


Figure 6-2 *Overall schedule for the siting and construction of the deep repository for demonstration deposition. The earliest possible times for the completion of the various stages are given.*

on, for example, transportation-related matters and the societal and geological premises for a deep repository in the municipality. With the aid of a feasibility study, both SKB and the municipality can – at an early stage and without committing themselves – obtain a preliminary idea of the premises and decide whether the possibility of siting a deep repository in the municipality is worth examining more closely.

In parallel with the general studies and feasibility studies that lead to the selection of candidate sites, the coming work on the candidate sites will be planned and prepared. A programme for geoscientific pre-investigations will be drawn up. The studies and analyses of the technical premises and of the repository system will continue and will be reported in a preliminary system and facility description. A preliminary environmental impact statement will be prepared and a programme for local involvement, information and socio-economic studies will be drawn up.

Table 6-1 provides a short summary of the planned content of the main reports to be prepared in the early part of Stage 1.

Table 6-1 *Main reports planned during Stage 1. General studies and feasibility studies.*

A *General studies and feasibility studies*
Content: Review of siting factors. Result of feasibility studies. Technical investigations. SKB's evaluation and selection of candidate sites.

B *Preliminary description of repository facilities*
Content: Preliminary description of the final repository system surface and underground facilities, flexibility in design and construction. Labour force needed in the different phases.

C *Programme for geoscientific pre-investigations*
Content: Investigatory strategy based on previous experience and results, measurement and data collection methods, evaluation methodology, quality assurance.

D *Preliminary environmental impact statement (MKB)*
Content: Overall MKB for the entire planned activity (detailed characterization, construction, operation, sealing and long-term phases). Conventional environmental impact and overview of radiological safety in connection with handling in the long-term.

E *Programme for local involvement, information and socio-economic studies*
Content: Proposal for forms of cooperation between SKB-municipality-local interests. Plan for contact/consultation with authorities, municipalities and local population. Local information offices. Information material. Possible measures for the development of local infrastructure and industry. Estimated effects on employment.

SKB's plans to prepare a preliminary description of repository facilities and an initial, preliminary environmental impact statement (MKB) means that preliminary information on this matter will be made available to authorities, municipalities and the general public, several years before the time that SKB must submit applications to obtain permits as prescribed in the NRL and KTL. This provides a good basis for promoting the kind of dialogue advocated in the legislation, in an unhurried manner, with municipalities, authorities and the general public concerned regarding which issues should be treated in the final MKB.

Based on the data obtained from the general studies and the feasibility studies, SKB will establish local offices and commence pre-investigations on a couple of sites. These investigations include:

a Geoscientific surveys and assessments in several stages from the ground surface and in boreholes. The goal is to determine the exact location of a rock volume for a deep repository and to preliminarily verify the suitability of the site.

b System studies for the surface and underground facilities. Planning and design work. Devising of site-adapted layouts. Analyses of environmental and safety aspects.

c Technical and socio-economic studies to shed further light on and determine the impact of the siting of a deep repository in the locality, on the community, the environment, the local economy and local industry.

d Studies of suitable modes and routes for transporting encapsulated spent nuclear fuel from CLAB to the deep repository.

When the pre-investigations at a site are begun, suitable forms should be established for giving the municipality and the citizens affected by the siting insight into the activities. The landowner's permission is required before pre-investigations are initiated at a site.

Parallel to and largely based on results from the geoscientific pre-investigations, preliminary design of the facilities will be carried out. The design of an industrial area above ground will be studied and the different functions and units will be specified.

The layout of the surface facilities, which is adapted to the local conditions, will be prepared. A preliminary layout of the underground facilities will also be prepared on the basis of the information obtained on the bedrock at repository depth. System and performance studies will also be carried out and will include the entire canister

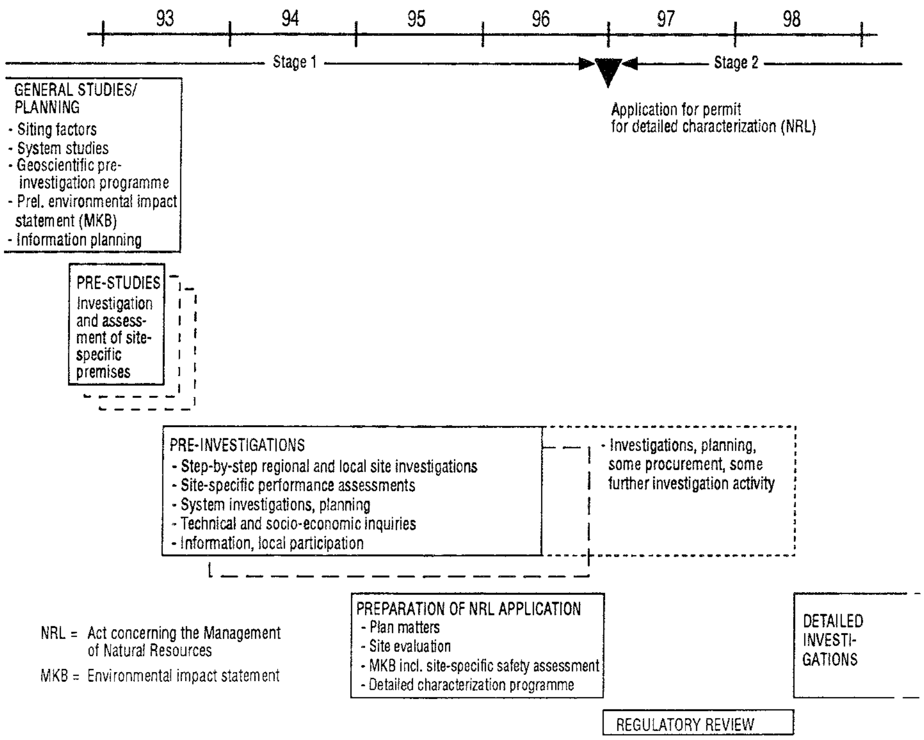


Figure 6-3 *Plan of activities and schedule for the siting of a deep repository during 1993-1998.*

handling chain, from the unloading of transport vehicles via control, interim storage and transportation down into the deep repository to final emplacement of the canisters.

Stage 1 will conclude with a compilation of all the necessary background material in an application under the Act concerning the Management of Natural Resources (NRL) for permission to carry out detailed characterizations. An environmental impact statement (MKB), a safety assessment and a programme for detailed characterization will be appended to the application.

6.4 STAGE 2. DETAILED CHARACTERIZATION

Detailed characterization entails building a tunnel and/or shaft down to that part of the rock where the deep repository is planned to be built. Below the tunnel/shaft and at repository depth, the rock will be characterized using methods and programmes developed and tested in the Äspö Hard Rock Laboratory, see the background report, "Äspö Hard Rock Laboratory". The goal of the detailed characterization is to:

- finally verify the suitability of the site for a deep repository,
- obtain background data for a detailed layout,
- obtain supporting data for an application for permission to build a deep repository for demonstration deposition.

Full-scale detailed characterizations should mainly only be initiated at the site, because such characterizations require considerable resources in the form of equipment, competence, and funds (on the order of SEK 500 million). SKB does not consider it reasonable to unnecessarily expend extensive efforts, resources and funds on an extra site which would then be abandoned, leaving excavated rock, empty tunnels, shafts and rock vaults. Only if there is reason to believe that the site selected for the detailed characterization would be unsuitable, should detailed characterizations be initiated at another site. The legal requirements on investigating various alternatives regarding siting and environmental impact statements will be met by the comprehensive data which will be obtained during Stage 1.

The technical and socio-economic studies begun in Stage 1 will be pursued in greater depth during Stage 2. The deep repository will be planned and designed. Safety, during operation as well as after sealing of the repository will be assessed and described in a preliminary safety report (PSR). SKB's establishment in the area will be expanded. Stage 2 will conclude with a compilation of all supporting documents for applications for a siting permit under the Act concerning the Management of Natural Resources (NRL) and a licence under the Act on Nuclear Activities (KTL). The applications will be submitted to the regulatory authorities.

6.5 STAGE 3. CONSTRUCTION OF A DEEP REPOSITORY FOR DEMONSTRATION DEPOSITION

This stage will include the expansion of the deep repository to a facility which is ready to receive encapsulated spent nuclear fuel for demonstration deposition. The rock excavation work can be carried out in a few years owing to the fact that a large part of the access drifts will already have been driven as part of the detailed characterization in Stage 2. The facility must have equipment to receive shipments of canisters with fuel, to emplace the canisters and emplace bentonite in the deposition tunnels.

Stage 3 will lead to a final safety report (FSR) in support of an application for an operating permit under the Act on Nuclear Activities.

If a permit is obtained, Stage 4 will commence: Demonstration deposition of encapsulated fuel lasting several years, plus the subsequent evaluation.

6.6 LEGISLATION, SUPERVISORY AUTHORITIES AND PERMITS

Nuclear activities in Sweden are mainly regulated by the Act on Nuclear Activities. This is primarily a safety law and the supervisory authority is the Swedish Nuclear Power Inspectorate (SKI). Provisions that regulate radiation protection are contained in the Radiation Protection Act and Ordinance with the Swedish Radiation Protection Institute as the supervisory authority.

External environmental protection is mainly regulated by the Act concerning the Management of Natural Resources etc (NRL) and the Environment Protection Act (ML). The Swedish Planning and Building Act (PBL) is the basic legislation regulating municipal planning. The applicable legislation has been compiled and analyzed in /6-2/.

6.6.1 The Act concerning the Management of Natural Resources etc (NRL)

The purpose of the NRL is to promote the reasonable use of natural resources for the benefit of society by making an overall judgement of all aspects concerned. The point of departure is that land and water areas shall be used in a manner that encourages good long-term management from ecological, social and economic viewpoints.

The NRL defines certain national interests and prescribes that areas involving such interests shall be protected from any measures which can be seriously detrimental to them. The precise extent of such areas shall be specified in the comprehensive plans of the municipalities. The NRL also stipulates that land and water areas which are especially suitable for energy production and waste management can be designated areas of national interest. These areas shall be protected, as far as possible, against measures which can seriously render their utilization more difficult. Classifying an area as being of national interest does not mean that all change to that area is prohibited. The municipal comprehensive plans shall indicate which changes are in conflict with the national interest associated with these areas and shall indicate the terms according to which such changes may take place.

A permit granted in accordance with the NRL may not contradict detailed development plans or area regulations. A municipality can also oppose the siting of a facility through a decision by the local municipal council. In other words, the municipality has the right of veto. However, the Government can, under certain circumstances, still grant the permit by making reference to the "national interest", Section 4, Article 3. This amendment of the NRL came into effect on July 1, 1990 and rescinds the municipal veto if:

- it is especially important that the facility be established, from the national standpoint,
- no other municipality with a suitable site is prepared to accept the site,
- no other site is considered to be more suitable.

SKB's approach and point of departure in this matter is that a deep repository will be sited in understanding and harmony with the municipality concerned.

6.6.2 Environment Protection Act and Water Act

The purpose of the Environment Protection Act is to provide protection against disturbances in the external environment, such as noise as well as airborne and waterborne pollutants or other disturbances that can occur in the utilization of land, buildings or facilities. The Act regulates the conditions under which activities resulting in an environmental impact can occur. The Act is not applicable to activities involving ionizing radiation. These activities are regulated by the Act on Nuclear Activities and the Radiation Protection Act.

The application, in accordance with the Environment Protection Act, for permission to construct a final repository for spent nuclear fuel is submitted to the National Licensing Board for Environmental Protection. If the Government has made a decision in accordance with the NRL, this decision is binding as regards the review of the application in accordance with the Environment Protection Act, i e the National Licensing Board for Environmental Protection does not have to review the suitability of the selected site.

The excavation of rock required for a 500 m deep repository can have a certain effect on the groundwater conditions at the site and therefore, a permit, in accordance with the Water Act will be required. The application is submitted to the Water Court within whose area of jurisdiction the deep repository is to be sited.

6.6.3 Environmental Impact Statement

Applications in accordance with the NRL and Environment Protection Act shall contain environmental impact statements (MKBs). A corresponding regulation has been proposed in the review of the Act on Nuclear Activities (KTL). An MKB is intended to form part of the basis for decision-making on the siting and design of an industrial facility. It shall be prepared by the applicant and be submitted in connection with the application. The structure and content of the MKB is determined by the nature and scope of the activity. It is up to the authority reviewing the application to decide if the MKB is sufficient or needs to be supplemented by additional information. SKB's plans for MKBs at different stages in the process of siting a deep repository are described in further detail in Chapter 12.

6.6.4 Municipal Comprehensive Plan.

Each municipality shall have an up-to-date comprehensive plan, covering the whole of the municipality's area.

The comprehensive plan shall indicate the main ways in which land and water areas are to be utilized and how physical development should take place. The municipal comprehensive plan is not binding for either authorities or individuals. The control of land use and of development within a municipality takes place through detailed development plans. The work on detailed development plans is mainly carried out by the municipality concerned, possibly with the cooperation of a developer. During the course of work, the municipality shall confer with the County Administrative Board, the property formation authority and other municipalities affected by the proposal. The municipality shall also be given the opportunity to consult with the parties legally concerned, tenants and residents affected by the proposal as well as with other authorities, associations and individuals who have a vested interest in the proposal.

The county administrative board supervises all planning and building activities in the county and shall cooperate with the municipalities in their planning activities. Planning and building activities for the whole country are under the general supervision of the National Housing Board.

6.6.5 Licensing during the various stages of the siting process

As illustrated by Figure 6-2, extensive reviews are carried out by the authorities on several occasions during the siting process.

At the pre-investigation stage, more comprehensive field work is started at the candidate sites. The minimum requirement for this work is that SKB should have access to the land where the investigations are to be carried out. This requires the permission of the landowners concerned.

The pre-investigations will be carried out in several stages. This means that deep boreholes will be drilled into the rock for sampling, measurements and possible trial pumping. It is possible that the bedrock may be uncovered to a certain extent, through the removal of the soil layer. Depending upon the extent of the measures taken and the local conditions, certain stages of the pre-investigation work may be affected by provisions in the Environment Protection Act, the Water Act, the Act for the Management of Agricultural Land or the Forestry Act.

The pre-investigation stage will be completed by SKB's applications to excavate tunnels or shafts to the intended repository depth to allow detailed characterization of the proposed deep repository site to be carried out. In connection with these applications, the suitability of the sites will be reviewed by various authorities.

From a purely formal perspective, an application to start detailed characterization work does not have to include any other activities than those covered by the concept of detailed characterization, i e the construction of shafts and/or tunnels and investigation work above ground and underground. However, since the aim of the detailed characterization is, if the results of the investigation are positive, to construct a deep repository on the site, it is natural to also include and describe in the NRL application, the environmental impact of constructing, operating and sealing a deep repository on the site. This means that a safety assessment based on the data obtained at the pre-investigation stage should also be attached to the application. Thus, the review by the authorities and the municipality may focus on:

1 Determining whether SKB's selection of site is acceptable.

2 Determining whether SKB can be granted a permit to carry out detailed characterizations.

3 In connection with the decisions made in 1 and 2 above, determining whether any of the data obtained indicates that SKB should refrain from carrying out the planned detailed characterization, e g because SKI, in its review comments, considers that the long-term safety requirements will not be fulfilled.

The detailed characterizations require significantly greater changes to the site than the pre-investigations. The land will be in constant use over a long period of time and the chances are relatively great that the repository will actually be sited there. During this stage, extensive work will be carried out on obtaining data for the siting and building permit. Applications for permits in accordance with the NRL, KTL, Environment Protection Act and Water Act will, therefore, have to be submitted. This is also the time that work on the detailed development plan will be initiated. An overview of the licensing process is presented in Figure 6-4.

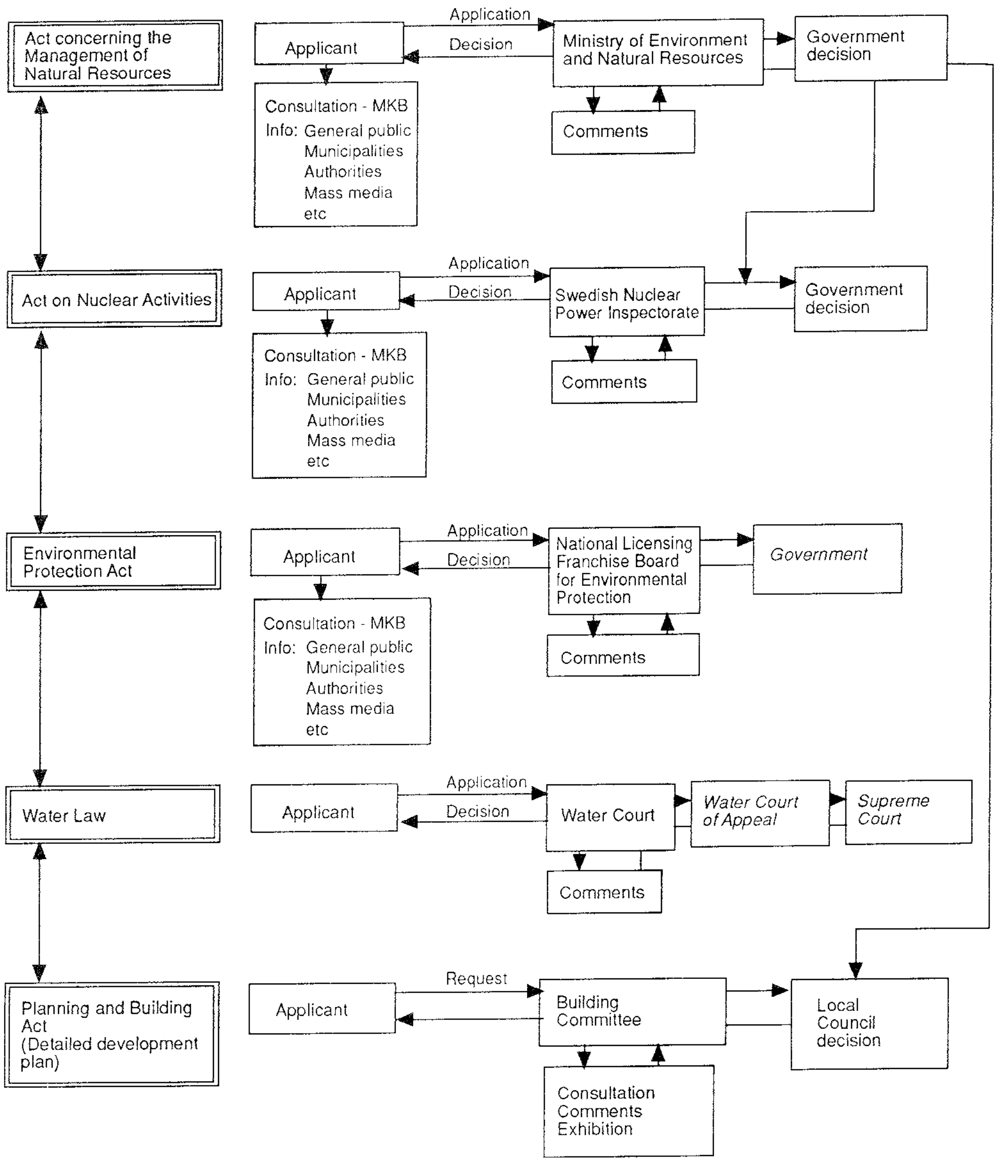


Figure 6-4 *Decision-making process as provided for in the legislation regulating the siting and construction of a deep repository*

7 FUNDAMENTAL CRITERIA AND SITING FACTORS

The site of a deep geological repository must fulfill certain fundamental criteria. In addition, a series of siting factors must be evaluated when the suitability of various sites is being evaluated. The criteria, premises and related siting factors are discussed in this chapter.

7.1 FUNDAMENTAL CRITERIA

The selection of candidate sites will be carried out in accordance with the fundamental criteria that must be made on a deep repository site from safety-related, technical, societal and legal viewpoints. It must be possible, by means of a safety assessment, to demonstrate for a selected site and selected repository system that the safety criteria stipulated by the regulatory authorities are met. It must be possible to build the repository and deposit the canisters in accordance with the intended technique. Siting, investigations and construction shall be carried out in such a manner that all relevant legal and planning criteria are met. And last, but not least, it shall be possible to carry out the project in harmony with the municipality and the local population.

7.1.1 Safety-related criteria

The fundamental safety-related principle for the deep repository system being planned by SKB is to contain and isolate the spent nuclear fuel in tightly sealed canisters that are deposited at a depth of about 500 metres at the selected repository site. The entire operation and system design is aimed at ensuring that this waste isolation will be achieved and will endure over a very long period of time so that the radioactive materials decay inside the canister and cannot escape. This means that the rock's most important safety-related function for a final repository is to guarantee stable conditions for the engineered barriers over a long period of time. SKB's geoscientific research and the safety assessment, SKB 91, show that the rock, in many places in Sweden, is capable of meeting this criterion.

In addition to this fundamental criterion, properties of the site which can provide additional barriers should also be taken into consideration. A list of such properties is presented in Table 7-1.

Table 7-1 *Safety-related functions linked to the properties of a deep repository site. Level 1 provides complete isolation of the waste. Level 2 counteracts the release and transport of radionuclides in the event of any existing or future canister defects. Level 3 contributes to low individual doses if the safety-related functions of Levels 1 and 2 have not been fully achieved.*

	Safety Function	Related Site-specific Factors
Level 1	Provide for long-term stable conditions for the canisters and bentonite clay so as to isolate the waste.	– Rock movements – Groundwater chemistry (reduced conditions at repository depth) – Risk for human intrusion
Level 2	Provide for slow dissolution of the exposed spent nuclear fuel and slow transport of any released radionuclides through the rock.	– Groundwater chemistry – Groundwater flow paths – Retardation through sorption/absorption along the flow paths.
Level 3	Provide for favourable conditions in receiving bodies	– Dilution conditions – Type of receiving body for groundwater (for example discharge of the groundwater into the sea or freshwater).

7.1.2 Technical criteria

The technical criteria that are made on the bedrock at the candidate sites are primarily connected with feasibility of construction. It shall be possible to build a repository at a depth of about 500 m on the chosen candidate site without encountering excessively great problems with collapse-prone rock volumes or major water seepage.

Another technical criterion which is also favourable from the viewpoint of safety is that the candidate site shall be easy to interpret, i.e. that the pre-investigations shall give such a result that rock properties of importance to feasibility of construction can be determined with a good degree of certainty. This is important in order for the repository to be designed as well as possible with a view towards long-term safety, at the same time as good knowledge of these structures is essential for being able to plan the configuration and location of the tunnel system and deposition holes.

7.1.3 Societal criteria

The main societal factors that must be taken into account in the siting process are plans for land use, transportation of spent nuclear fuel, public opinion, landowners and infrastructure. These factors are of great importance to the suitability of an area and are, in practice, the deciding factors once the technical and safety-related criteria have been satisfied.

7.2 DISCUSSION OF PREMISES AND SITING FACTORS

Within Stage 1 of the siting process, SKB has initiated studies to shed light on a series of different factors which, in some way, should be taken into consideration before selecting the sites for pre-investigation. The purpose of this work is to present a clear picture of the total set of conditions which must be met for the siting and construction of a deep geological repository in Sweden. According to SKB, sites can be found in most parts of Sweden with conditions which are favourable for satisfying the criteria. However, a really clear picture of all the premises and conditions which exist cannot be obtained until concrete area- and site-specific investigations of both the societal and the technical/geoscientific aspects are carried out. With the aid of the data which are compiled on different siting factors, it will be possible to place the candidate areas in a broader national and regional perspective. Important geological, technical and societal aspects of the selection of a site for a deep repository are discussed and summarized below.

7.2.1 Geological premises

General

With its location within the Baltic Shield, Sweden's geological conditions are favourable for hosting a deep geological repository. This, and other shields, belong to the most stable areas in the world. Most rock types in the Baltic Shield were formed between 1500 and 2000 million years ago, and, at least over the past 650 million years, the Swedish crystalline bedrock has been very little affected by tectonic events. Therefore, the bedrock provides a good guarantee for the long-term stability of a deep repository. Mines and other underground facilities also show that the bedrock is well suited to the construction of a repository at a depth of 500-1000 m. As shown in Figure 7-1, Sweden consists, to a large extent, of crystalline bedrock.

Consequently, the crystalline bedrock allows for a well-functioning and safe repository performance during the time that the spent nuclear fuel is toxic. During this time, the quantity of radioactive substances will successively decline and reach the same level of toxicity as uranium ore after a period of about 100 000 years. Seen from a geological perspective, this is a short period, and one which it is possible to predict. For example, with a high degree of certainty, we can assume that this period will be characterized by a considerably colder climate, with several periods of tens of thousands of years when parts of the country, or the entire country will be covered by inland ice /7-1/. These ice ages are the most important geological events which can possibly affect a deep repository over the next 100 000 years. Other geological processes, such as land uplifts and erosion, are not expected to affect the repository. Furthermore, no important changes are expected in the directional movements of the continental plates /7-2/ or in the size of the plate-tectonic forces.

The possible consequences of future ice ages on a deep repository have been studied in SKB 91. This assessment has not revealed any negative effects from the standpoint of safety. Instead, it has indicated that an ice age can be considered to be a favourable event from the standpoint of safety, since a larger part of the glaciation period will be characterized by none or very little groundwater flux in the rock.

As has been pointed out by the National Board for Spent Nuclear Fuel (SKN) in its review comments to R&D Programme 89, it would also be possible to construct the repository in the crystalline bedrock underlying areas covered by sedimentary rock types which are not too thick. Such areas can mainly be found in the mountain chain, in Skåne, on Öland-Gotland as well as under the sea outside the southern and southeastern part of Sweden, see Figure 7-1.

Such a location for the repository may have certain advantages, with regard to the low groundwater flux, among others. However, since areas with crystalline bedrock without sedimentary cover offer a satisfactory level of safety, there is no reason to particularly seek out sediment-covered areas as repository sites.

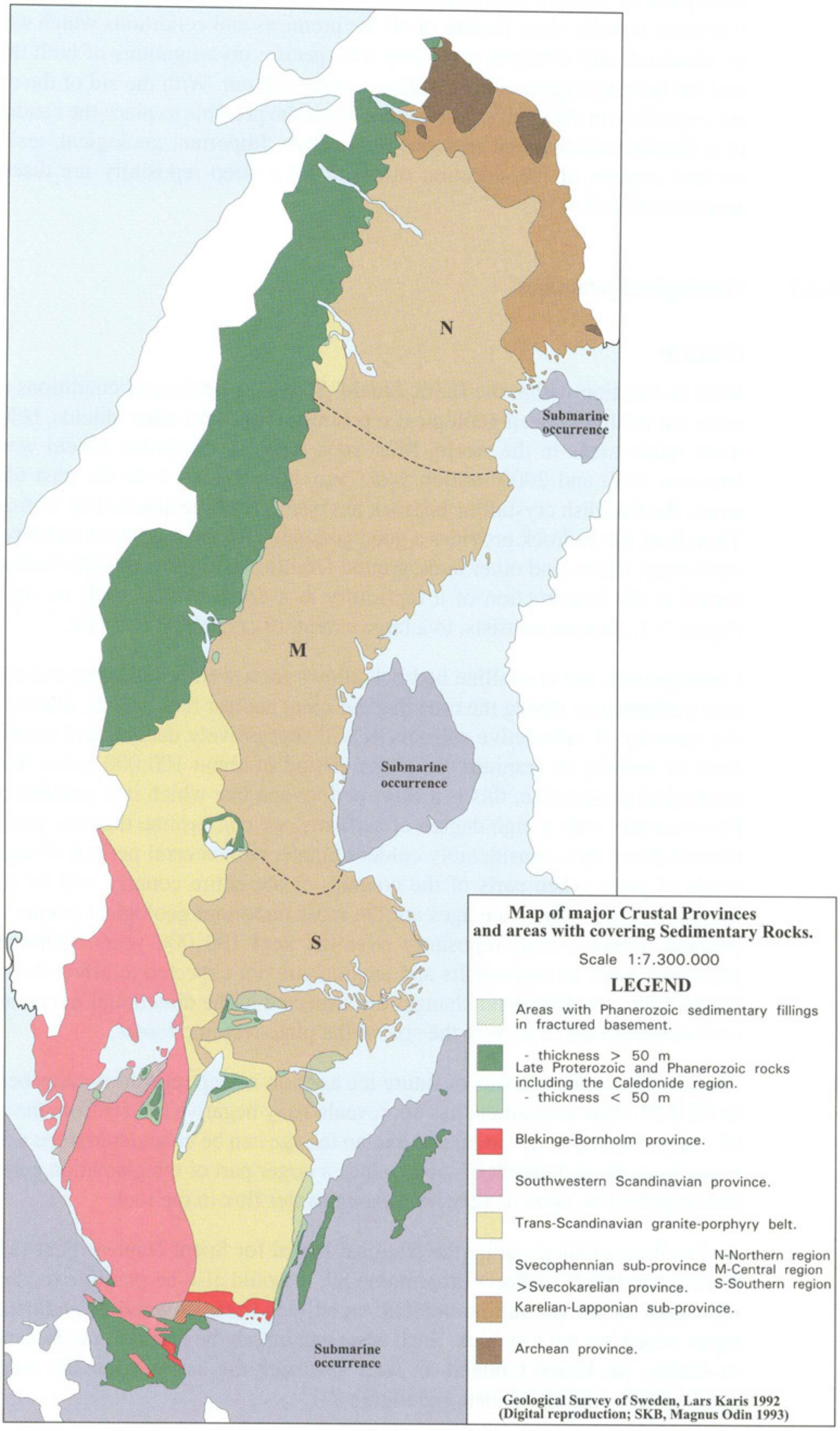


Figure 7-1 *Areas of crystalline Precumbrian bedrock and Phanerozoic (Cambrian-Devonian, Permian-Tertiary) sedimentary rocks in Sweden, including the Swedish continental shelf. ("Submarine occurrence" indicates the submarine occurrence of sedimentary rocks).*

Gabbro has, on several occasions and as recently as in the review comments to R&D Programme 89, been designated a potentially suitable rock type for hosting a deep repository. Low water permeability and an advantageous chemical-mineralogical composition with regard to radionuclide transport have been mentioned as particularly favourable properties. A summary of Swedish and foreign experience /7-3/ shows that the positive significance of these properties is uncertain and that there are other properties which detract from the suitability of gabbro, such as its ore potential. An important observation is that there are few, if any, large bodies of gabbro which meet the geological criteria on homogeneity and size, and at the same time, are located in areas which are suitable from the societal viewpoint.

Long-term stable environment

As was previously mentioned, safety assessment SKB 91 has shown that the most important role of the rock in the repository system is to ensure a long-term stable environment for the copper canisters and bentonite clay. Above all, it is important that the groundwater should be reducing and that the repository should be located so that any rock movements in the area do not affect the canisters.

In these aspects, Swedish crystalline bedrock provides favourable conditions. Samples taken from deep boreholes in the study sites and in Stripa and the Äspö Hard Rock Laboratory indicate that the groundwater is reducing everywhere at a depth of 500 m /7-4/. Furthermore, since the concentrations of most of the substances are controlled by solubility limitations, it is not possible to predict any important future changes, even if human influence on the chemical conditions of the atmosphere continues. Therefore, regardless of where the deep repository is located, the criterion of reducing groundwater at repository depth is expected to be fulfilled.

The risk of repository damage due to rock movements, faults, during its functional lifetime, is also very small. This is due to the fact that existing faults which intersect the bedrock form networks which can be reactivated when subjected to new loads. In most cases, these faults were formed early on in the geological history of the earth (more than one billion years ago) and exist on all scales – from the local scale, with lengths of a few hundred metres, to the regional scale, with lengths of 500 km or more.

One example of such a fault is the Lansjärv fault in Norrbotten where the fault movements occurred as recently as in the deglaciation period of the most recent ice age. Extensive studies show that these movements were actually the last in a long history of reactivations, see background report "Detailed R&D Programme 1993–1998", Chapter 6. However, reactivations of existing fracture zones do not present a problem to the performance of the repository, since fracture zones in the vicinity of the repository will be identified during the pre-investigations or when the repository is being constructed. Since no spent nuclear fuel will be deposited within or adjacent to a fracture zone, no canister can be damaged if a reactivation should occur.

Sweden, with its location within the Baltic Shield, is a country with very low seismic activity. There is no reason to expect any major change in this activity during the functional lifetime of the repository, possibly with the exception of short spans of time during the deglaciation of future inland ice sheets. A recently completed summary of tectonic processes and seismicity in Sweden indicates that the current seismicity is largely a result of the land uplift after the last ice age /7-5/. However, other researchers claim that the present seismicity is largely due to plate-tectonic forces /7-6/.

During recent years, it has been possible to link more and more earthquakes to large-scale lineaments which are assumed to represent major fracture zones /7-7/.

Thus, these observations also support the theory that Swedish earthquakes are triggered in old fracture zones.

Low groundwater flux

As was previously mentioned, it is desirable to have low groundwater flux between a deep repository and the surface. The reason for this is to obtain optimal benefit from the extra barrier provided by the rock through its ability to sorb most of the dissolved substances, and thereby, retard the transport of radionuclides.

Since radionuclides can only be transported in the groundwater from the repository to the surface, it is favourable if a repository site is found to have the necessary conditions for low groundwater flux, long groundwater transport times and a large contact surface between the water and rock for sorption and matrix diffusion. The reason for this, is to minimize the potential transport of radionuclides from the repository to the ground surface. Low groundwater flux and long flow paths depend upon topographical and other conditions. These conditions can be studied on a regional and local scale during the siting process and certain conclusions can be drawn at an early stage regarding such factors as the hydraulic gradient and the distance between the repository and the discharge area. To a certain extent, knowledge of hydraulic conditions can also be obtained using data from existing wells drilled in rock. These wells can also be used to study the extent of the occurrence of areas with saline groundwater - a factor which can be an indirect indication of low groundwater flux.

It is important to have a good knowledge of possible nuclide transport pathways in the bedrock and their hydraulic properties. This is particularly the case for the flow paths existing between the repository area and the discharge area. Such knowledge can be much more easily obtained if the geological and tectonic conditions at the selected site are not complex. Thus, homogeneous bedrock and tectonic conditions which are obviously regular, are favourable factors.

7.2.2 Technical premises

Sweden's geological conditions for the construction of facilities in the rock have been found to be favourable in an international comparison. A fundamental premise is strong rock types which will allow the construction of stable openings in the rock. The crystalline bedrock which comprises most of Sweden adequately satisfies this condition. On the other hand, the rock types in Swedish mountain chains and the sedimentary formations found in Skåne, Öland and Gotland have generally been found to have less adequate and more varied structural engineering properties than the crystalline bedrock.

As regards technical resources and expertise within the area of rock engineering, Sweden has long since occupied a leading position, seen from an international perspective. For natural reasons, these resources are mainly related to engineering in hard rock and are based on extensive mining operation, construction of hydroelectric power stations and considerable construction volumes for underground storage and infrastructural purposes. In addition, Sweden is a major and competitive industrial producer of rock mining and rock-blasting equipment. Since the 1970s, the rock engineering industry has suffered a decline due to reduced volumes in both the mining and construction sectors. To a certain extent, the Swedish rock construction industry has been able to compensate for this by undertaking projects abroad. Even if the decline has had a clearly negative effect on capacity, it must still be concluded that the availability of the human and technical resources required for the design and construction of a deep repository in crystalline bedrock is more than adequate within the industry.

Compared with mines or facilities for storing oil, a deep repository involves small or medium-sized rock vaults. This increases the possibility of achieving good stability and vastly facilitates practical construction work. Therefore, it can be generally concluded that the rock structures required by a deep repository can be achieved by the technology that is available today. However, it should be emphasized that rock construction is always different from conventional construction engineering, in the sense that the properties of the construction material vary and can never be completely determined in advance. This means that the flexibility of being able, at a very advanced stage of work, to adapt the repository configuration to local conditions must be maintained. In addition, it should be noted that a deep repository involves rock structures at depths which are considerably greater than the normal depths which are dealt with in rock construction work.

This may require special consideration of external factors whose significance is heavily dependent upon depth. Such a factor is the occurrence of groundwater under high pressure, which can cause problems in connection with rock excavation. Another is the fact that the mechanical loadings in the rock mass increase with depth. This can lead to the establishment of special criteria on design and reinforcement of the structures. Experience from the mining industry is of particular interest in this respect, since it includes excavation at depths corresponding to that of a deep repository.

On the national scale, no essential difference in these factors can be seen in the various areas containing bedrock in Sweden. On the other hand, these factors will be important on the local scale. Factors which determine the feasibility of construction in a particular area are rock type, fracture frequency, location and nature of fracture zones, water-bearing tendencies, size and direction of rock stresses and mechanical properties in the repository bedrock. These factors can be responsible for considerable variation in the rock when it is used as construction material. Factors affecting the predictability of the properties of the rock are exposure, simple and homogeneous bedrock conditions and a regular system of fracture zones.

7.2.3 Societal premises

The societal premises which, in the first instance, must be taken into consideration when siting a deep repository are the plans for land use, transportation of spent nuclear fuel, public opinion, landowners and infrastructure. These factors are of great importance to the suitability of an area, and are, in practice, deciding factors once the technical and safety-related criteria have been fulfilled.

Land use

About 6% of all land in Sweden is set aside as nature conservation areas. No development may take place within these areas. If the concept is expanded to include all areas which are, at present, considered to be of national interest for environmental protection, Sweden consists of almost 22 % of such areas /7-8/. Even if it were possible to obtain a licence to develop several of the latter areas, special reasons must exist for the siting of a deep repository in these areas. This is also the case of predominately agricultural areas.

The NRL mentions certain well-defined coastal, mountain and catchment areas as well as river valleys where direct guidelines are provided for land use and which must be taken into consideration in the siting process. Other areas which must be taken into account in the siting process include areas protected for military and cultural purposes, areas which are of archaeological interest and recreation areas.

The county's nature conservation plans and the municipality's comprehensive plans will be of importance when conducting studies on a more local scale. The latter show the plans for land and water use, physical development and the locations of the areas of national interest within the borders of the municipality.

Transportation

The canisters containing spent nuclear fuel must be transported in special containers from the encapsulation plant to the deep repository. Marine as well as road and/or rail transportation can be adopted.

In Sweden, spent nuclear fuel is transported by ship between the nuclear power plants and the harbour at CLAB, see Figure 5-2. Other countries, such as Germany, France and Great Britain, have had considerable experience of transportation by rail and road.

The freight containers currently being used are designed to transport spent nuclear fuel which has only been stored a number of months after removal from the reactors. Shipments to the deep repository will comprise encapsulated spent nuclear fuel which is about 40 years old. Such shipments require a specially adapted freight container to transport the canisters which weigh about 20 tonnes.

If transportation by road or rail is adopted, studies of what is required to improve existing roads and/or railways to manage the heavy shipments of spent nuclear fuel must be carried out. Depending on the location of the deep repository, it may also be necessary to build new roads or railways along some part of the route. Public opinion and attitudes in the municipalities affected by the shipments must be taken into consideration. The cost of transporting the waste will depend upon where the deep repository is located.

The various aspects of the transportation of spent nuclear fuel which have been briefly treated above must all be taken into account when deciding where to locate the deep repository. The criterion of safe transportation can be fulfilled, by applying specially adapted techniques and by making the necessary investments, at all sites which may be considered. However, those aspects relating to cost and public opinion may be strongly site-specific.

7.2.4 Summary of the most essential siting factors

Geological, technical and societal siting factors will be taken into account in the siting of a deep repository for spent nuclear fuel.

Some of the siting factors are criteria which the site must fulfill. However, most of the factors lie in the range between favourable and unfavourable. Since ideal areas with only favourable factors do not exist, the candidate sites must be selected so that they appear to be suitable when they are judged as a whole.

It is important to note that most unfavourable factors can be compensated for by means of different remedial measures. For example, a heterogeneous bedrock or a low degree of surface rock exposure can be compensated for by increased drilling. A lack of, or shortcomings in the infrastructure can be compensated for by the construction of railways, roads, housing etc. These compensations do lead to higher total costs for the deep repository, however, which must be weighed against the advantages of the site.

Table 7-2 provides a short summary of some important siting factors.

Table 7-2 *Summary of some important siting factors*

Siting factor	Comment
Technical/geoscientific	
Long-term stable environment	The repository should be situated in parts of the rock that do not comprise weak zones of fractured rock in which significant future fault movements could be triggered. The rock volumes used for the repository should not contain pay minerals or suchlike since these could lead to future intrusion which might disturb the safety barriers. The groundwater at the selected site/depth should have long-term stable chemically reducing conditions.
Safety	The rock shall comprise an extra safety barrier through its capacity to absorb and retain any released nuclides. This capacity is dependent upon groundwater conditions (flows, flow paths), groundwater chemistry and retardation mechanisms along the flow paths. These conditions can be allowed for by taking into account factors such as hydraulic gradient, distance between proposed repository site and discharge area, presence of water-bearing fracture zones and vein minerals, and presence of saline groundwater.
Feasibility of construction	The feasibility of construction at a particular site is determined by the location and nature of fracture zones, the presence of rock types with a tendency for collapse or water-bearing, size and orientation of rock stresses and mechanical properties of the bedrock.
Predictability	It is an advantage if a site is easy to interpret, i.e. permits a high certainty in prediction of bedrock conditions between investigated parts of a site. Predictability is dependent upon degree of exposure and bedrock conditions.
Societal	
Land use	Consideration shall be given to areas of national interest for nature conservation, restricted areas, culturally protected or archaeologically interesting areas, etc. Careful attention shall be given to the counties' nature conservation plans and the municipalities' comprehensive plans. The impact of population density, area-based enterprises (e.g. forestry, animal husbandry, aquaculture, agriculture) etc. shall be studied. Areas with planned industrial land can be of particular interest.
Transportation	It is technically possible to transport the waste in a safe manner to all potential sites in Sweden. Safety, logistics, need for new investments, public opinion, and costs will be investigated for potential sites.
Infrastructure	The need for and influence of existing infrastructure and local enterprise will be clarified for potential sites.
Public opinion	Good cooperation with parties concerned is important. The municipality and the local populace will receive information and be given an opportunity to follow and offer viewpoints on the work.

8 PREVIOUS SITE INVESTIGATIONS

In Sweden, ten sites have been investigated to study the geological, hydrological and geochemical properties of the bedrock at these sites and to determine whether they fulfill the conditions to host a safe repository. This chapter examines the basis for the selection of these sites and the main results obtained from the investigations. The chapter concludes with a discussion of the experience gained and the conclusions which can be drawn prior to the future siting of a deep repository.

8.1 INVESTIGATIONS INITIATED BY THE AKA COMMITTEE

Site investigations within the Swedish nuclear waste programme started as early as 1975 with the investigation of the Pellboda area in Västerbotten, see Figure 8-1, by the Geological Survey of Sweden (SGU) on behalf of the AKA Committee /8-1/. The site was selected because it contained few fractures and was generally found to be suitable from the point of view of rock engineering, and consisted of paragneiss which was considered to have less groundwater flow compared with granite.

The purpose of the investigations was primarily to determine whether methods used for ore prospecting could also be used to identify water-bearing fracture zones of significance to a deep repository. With this aim, geological mapping and geophysical ground measurements were carried out. The fracture zones that were found were checked by short boreholes. Since fracture zones could be detected in all the boreholes, the conclusion was drawn that the existing methodology could be adequately applied to site investigations concerning the final disposal of nuclear waste.

The AKA Committee recommended that geological studies of sites suitable for a final repository should be initiated immediately.

8.2 INVESTIGATIONS IN CONNECTION WITH THE STIPULATION ACT

Prior to the startup of further nuclear reactors, the Riksdag (Swedish parliament) passed the Stipulation Act which included a requirement on reactor owners to demonstrate how and where an absolutely safe final disposal of high level waste or spent, non-reprocessed nuclear fuel could be carried out.

In order to demonstrate this, SKB conducted investigations between 1977-1979 at three sites – Sternö /8-2/, Kråkemåla and Finnsjön /8-3/. At each site, several holes were drilled to a depth of 500 m where the permeability of the rock and other factors were determined. These three sites were close to existing nuclear power plant sites, which was considered advantageous for the completion of the investigations in the short time available. The exact location of the study sites was determined by landowner-related factors combined with the geological condition that the bedrock should be well-exposed and consist of granite or gneiss with few fractures.

The result of the investigations was that Sternö demonstrated the most suitable rock conditions. At Finnsjön and Kråkemåla, fracture zones were found which limited the available rock volume for hosting a repository.

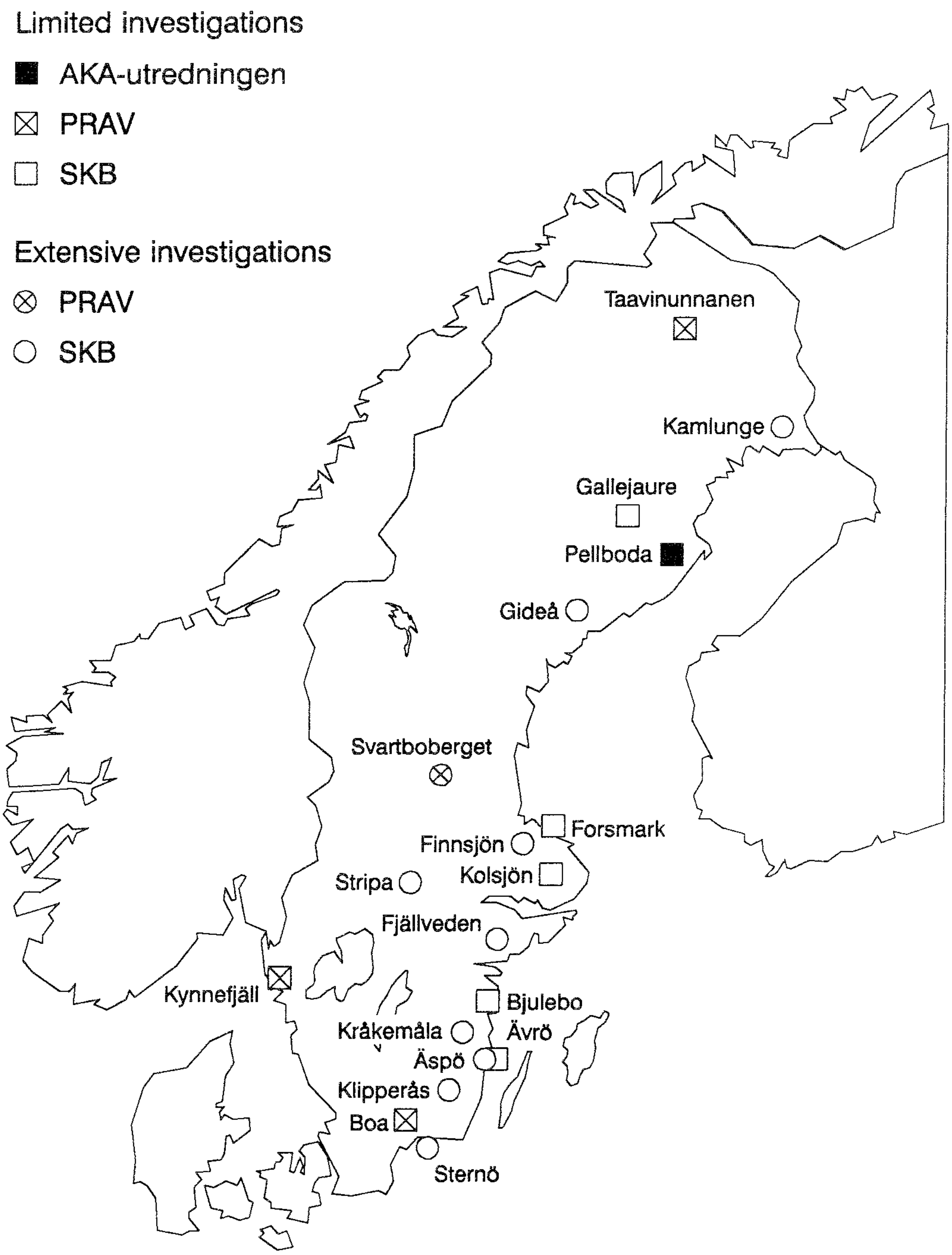


Figure 8-1 *Swedish sites where field work has been conducted, within the Swedish nuclear waste program, to gain knowledge of the properties of Swedish bedrock and/or to develop and test methods of investigation. The candidate sites will not necessarily be selected from these sites. Candidate site selection will be based on the general knowledge acquired from investigations at these sites.*

8.3 STUDY SITES INVESTIGATED BY PRAV

In parallel with the granting of the startup permit for the Ringhals 3 and 4 reactors as well as the Forsmark 1 and 2 reactors by the Government in 1979 and 1980, the site investigations continued under the management of the state-owned National Council for Radioactive Waste (PRAV).

The selection of suitable study sites was achieved systematically and was based on the whole of Sweden. The aim was not to locate a site for a deep repository, but to obtain data from great depths in various areas all over Sweden. These data were considered to be necessary to obtain an understanding of the variation of essential properties and conditions, such as hydraulic conductivity and the redox conditions of the groundwater.

Due to the positive experience gained at Sternö and from tunnel and rock cavern construction, the first reconnaissance studies mainly focussed on gneissic areas in southern Sweden. The studies were carried out by SGU. Suitable sites were selected primarily on the basis of geological criteria which included:

- high degree of exposure,
- flat topography,
- low fracture frequency,
- sparsely occurring large fracture zones,
- homogeneous geological conditions,
- low seismic activity,
- low water-bearing capabilities (well data).

The reconnaissance studies recommended two sites – the Boa site in Blekinge and Kynnefjäll in the county of Bohus. However, it was found that the first of these two sites was owned by a large number of private landowners. After initial consultations with some of these landowners, which yielded negative results, the Boa site was rejected as a study site. However, a permit was obtained to investigate Kynnefjäll and geological and geophysical mapping was carried out during 1979. However, when drilling was about to be initiated in 1980, it was suspended due to demonstrations at the site. No work has been carried out at Kynnefjäll since then.

Reconnaissance work in 1980 resulted in the selection of Svartboberget in Hälsingland. Unlike previous reconnaissance studies, this site was largely selected on the basis of interpretations of aerial geophysical photos. This meant that less emphasis was placed on several of the siting criteria mentioned above. The geological criteria made on the site were that the bedrock should consist of veined gneiss and that there should be sparsely occurring large fracture zones as well as the criterion that the potential site should have an surface area of at least 4 km^2.

In parallel with the selection of Svartboberget, reconnaissance work was carried out to locate a suitable study site containing gabbro rock. In 1981, these studies resulted in the selection of the Taavinunnanen gabbro in Norrbotten, mainly on account of its large area and vertical size combined with a high degree of exposure and a low frequency of lineaments.

8.4 STUDY SITES INVESTIGATED BY SKB

In 1982, the responsibility for study site investigations was transferred from PRAV to SKB. The investigations in Svartboberget and Taavinunnanen were in full progress at this time. Thus, the final work at these two sites was conducted under the management of SKB.

The results from the eight cored boreholes, 350–800 m deep, which were drilled in Svartboberget showed that the bedrock was less suitable for a repository. This was mainly due to the occurrence of dipping fracture zones which severely limit the available volumes of good rock. The occurrence of graphite in quantities which would be of interest for future mining activities was also a negative factor. The gabbro at Taavinunnanen was found to be intersected by steeply-dipping and permeable granitic dykes which also severely limit the available volumes of good rock.

Prior to submitting the application to startup the Oskarshamn 3 and Forsmark 3 reactors in 1983, a new safety assessment, KBS-3, was required. During 1981, reconnaissance studies were carried out which resulted in the selection of Fjällveden in Södermanland /8-4/, Gideå in Ångermanland /8-5/ and Kamlunge in Norrbotten /8-6/. The geological criteria mentioned in Section 8.3, except for the lower emphasis placed on the significance of seismic activity, were taken into account in the selection of these sites. The criterion of no more than one landowner of the study site had been added to facilitate the investigation work.

Neither Fjällveden, Gideå or Kamlunge entirely met the geological criteria mentioned above. This was particularly true of Kamlunge which has heterogeneous bedrock and a heavily marked topography. However, reconnaissance boreholes drilled to a depth of 700 m in all the sites showed favourable deep rock conditions. Thus, SKB decided to conduct complete investigations of the three sites. The results are included in the KBS-3 study together with the results from Svartboberget. The conclusions from the investigations showed that Fjällveden, Gideå and Kamlunge were suitable as repository sites, except for certain supplementary investigations which were required for Fjällveden. Svartboberget was considered to be less suitable.

The last study site which was investigated by SKB was Klipperås in Småland /8-7/. The site which consists of Småland granite is located in a predominately flat region which was considered indicative of a low groundwater flow at repository depth.

The flat topography with an evenly thick moraine layer meant certain disadvantages from the point of view of the investigation. Almost no observations could be directly made of exposed rock and only a few lineaments could be distinguished which could be linked to underlying structures in the rock. Even if these disadvantages were partly compensated for by an expanded ground geophysical and drilling programme, uncertainties still remain concerning the geological and hydrological models of Klipperås which, if the site were to be interesting in the future, must be compensated for by further investigation /8-7/.

Figure 8-2 shows regression curves of hydraulic conductivity deep in the rock mass (i.e. the rock outside the fracture zones) for the Fjällveden, Gideå, Kamlunge, Klipperås and Svartboberget study sites. Even if these regression tendencies must be seen as rough generalizations, there is, in general, no major difference between the sites, with the exception of Klipperås. This is the case, in spite of the fact that the sites are located in completely different parts of Sweden and within different geological environments. The somewhat higher conductivity of Klipperås may depend on the uncertainties mentioned above which have resulted in the inclusion of data from fracture zones in the curve for this site /8-7/. Even if the sites are generally found to be hydrologically similar, major local differences exist within each site which are of great significance to an optimal technical and safety-related repository design. For example, narrow vertical and permeable gneissic granite dykes in Fjällveden may mean that a repository should be divided into several parts, while a horizontal, water-bearing fracture zone in Kamlunge may mean that the repository should be located at a greater depth than that which would otherwise be the case. The conclusion is that it is the local conditions at the site which determine whether the site is suitable for a deep repository.

Safety assessment SKB 91 /8-8/ has shown that a safe final repository can also be located in the Finnsjön area. This site has, in previous evaluations, been judged to be less suitable than some of the other sites studied.

8.5 SUMMARIZING COMMENTS

The reconnaissances for selecting the study sites which were conducted during 1979–1985 comprised general evaluations of almost 1 000 sites scattered all over Sweden. On the basis of geological and non-geological (landowner-related factors) siting factors, ten sites were selected as suitable for further investigation. Complete site investigations were carried out on eight of these sites. All the sites studied probably contain rock which is a suitable host for a repository. However, differences exist which make the sites more or less suitable.

An important observation is that suitable, or less suitable sites cannot be attributed to any particular region or any particular geological environment. Furthermore, there is no correlation between less suitable sites and seismic activity. Instead, it is the local conditions of the site and the surrounding region which determine the suitability of a site.

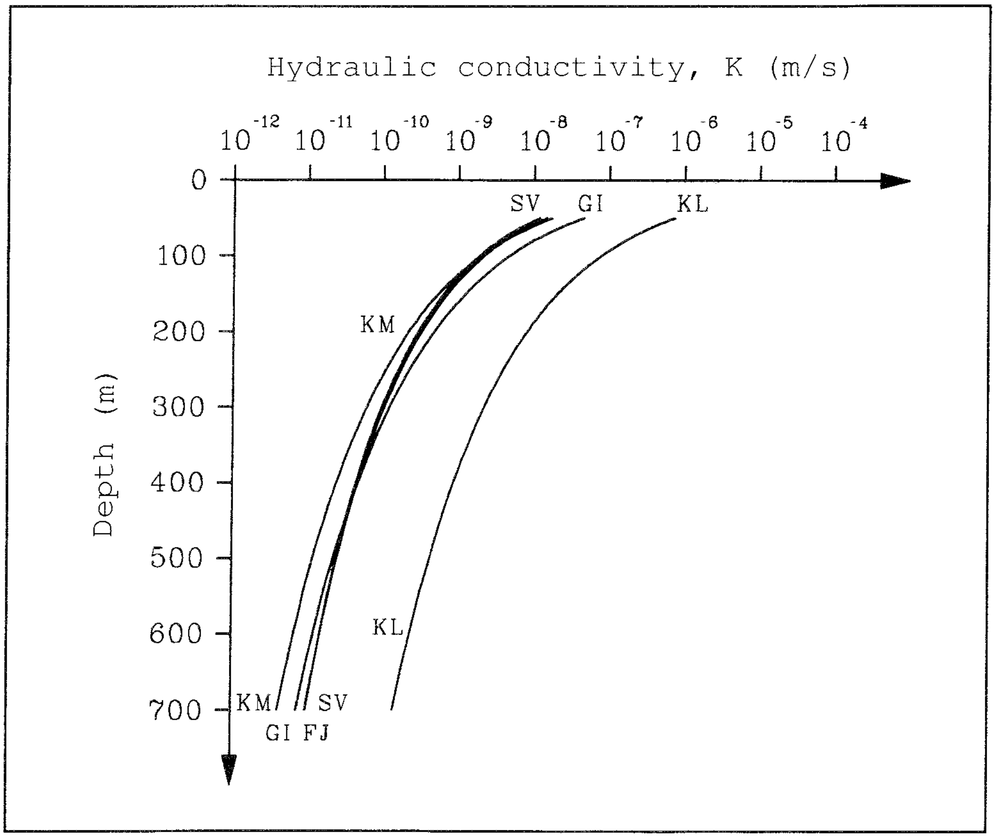


Figure 8-2 *Hydraulic conductivity (permeability) in the rock mass, excluding fracture zones from the Fjällveden (FV), Gideå (GI), Svartboberget (SVF), Kamlunge (KM) and Klipperås (KL) study sites.*

9 PREVIOUS EXPERIENCE OF SITING NUCLEAR WASTE STORAGE FACILITIES

There has not been any real siting activities for the deep repository before the start of the siting project that SKB set up in the autumn of 1991. On the other hand, a large body of material, especially on the geoscientific issues, which are of direct relevance to a future site selection process, has been compiled as can be seen from the previous chapter.

This chapter provides a summary of experience already gained in Sweden of siting facilities for nuclear waste or connected to nuclear waste and the discussion which has so far taken place regarding the siting of a deep repository.

9.1 SITING OF SKB'S EXISTING FACILITIES

SKB is currently operating three facilities within the existing system for management of and research concerning nuclear waste. These are:

- The central interim storage facility for spent nuclear fuel (CLAB) at Oskarshamn Nuclear Power Station.
- The final repository for radioactive reactor waste (SFR) at Forsmark Nuclear Power Station.
- The Äspö Hard Rock Laboratory outside Oskarshamn Nuclear Power Station.

The first two are nuclear facilities that have been sited and constructed in accordance with legislation applicable at the time, chiefly the Planning and Building Act (PBL) and the Atomic Energy Act. Siting and construction of the Äspö Hard Rock Laboratory has been approved under the Act concerning the Management of Natural Resources etc. (NRL).

9.1.1 Siting of CLAB

The need for a central Swedish facility for interim storage of spent nuclear fuel was identified by the AKA Committee, which recommended that the possibility of siting such a facility near to a nuclear power plant, primarily Forsmark or Oskarshamn, should be investigated.

Feasibility studies were carried out on the siting of the facility in the areas near to Forsmark nuclear power plant, Oskarshamn nuclear power plant and Studsvik nuclear research centre. The deciding factor in the selection of these three sites, from the very outset, was the fact that the nuclear activities which were already established were considered to be a considerable asset. The other nuclear power plant sites (Ringhals, Barsebäck) were not considered as suitable from the standpoint of planning or rock engineering.

Feasibility studies of the Forsmark, Simpevarp and Studsvik sites indicated that the bedrock conditions at all three sites were adequate, even if the Studsvik site would require more extensive reinforcement work. Also, only small differences in non-geological factors were found. Two alternatives were discussed for the Simpevarp peninsula, Ävrö and an area west of the nuclear power plant.

On the basis of the feasibility studies, the former SKBF (Svensk Kärnbränsleförsörjning AB, now SKB) submitted (Nov. 1977) an application, in accordance with the Building Act which was valid at that time, for siting the facility at one of the above-mentioned sites. The Ministry of Housing subjected the application to extensive external review, where several of the reviewing bodies either approved the application or did not submit any comment. The three municipalities concerned also approved the application. However, several reviewing bodies commented on disadvantages of the Studsvik site, arising from the lack of the required harbour, the large quantities of shipped waste compared with other alternatives and the proximity to a predominately recreation area and to areas of national interest from the viewpoint of nature conservation and outdoor life.

As regards the two alternative sites on Simpevarp, Oskarshamn municipality and the National Environmental Protection Board recommended the area west of the nuclear power plant with regard to nature conservation interests.

After an overall review, the Government found (Dec. 1978) that "in the first instance, the area west of the nuclear power plant on Simpevarp should be considered as the site of the storage facility for spent nuclear power plant requested in the application". The handling process for the siting and construction of CLAB is summarized in Table 9-1.

9.1.2 Siting of SFR

The idea of a central final repository for low- and intermediate-level waste was also presented by the AKA Committee and feasibility studies for such a facility were initiated by the then existing National Council for Radioactive Waste (PRAV). This work was assumed by SKB in 1980. As in the case of CLAB, the nuclear installation sites were studied, primarily Forsmark, Simpevarp and Studsvik. Similar conclusions were also drawn, i.e. locating the facility at the Forsmark and Simpevarp sites, in particular, was considered possible. For labour market reasons, Forsmark was finally selected even though the transportation work required would have been somewhat less extensive if the facility had been located on Simpevarp.

SKB carried out the necessary investigations and studies in order to be able to submit, in March 1982, an application for a building permit in accordance with the Swedish Planning and Building Act, Atomic Energy Act and Environment Protection Act. Table 9-2 is a summary of the licensing process.

The coordination of the various reviews of SFR was satisfactorily carried out, according to the committee set up to review nuclear legislation. At an early stage, the municipality concerned had to submit a preliminary statement in accordance with the Building Act. Then, the technical review was carried out, in accordance with the Atomic Energy Act, by SKI and, in accordance with the Radiation Protection Act, by SSI. When the technical review had been carried out, the matter was again referred to the municipality for final review. Thus, in preparation for the final review, the results of the technical review were made available to the municipality. After the municipality had granted its approval, the Government decided to grant the permit in accordance with the Building Act and the Atomic Energy Act.

Table 9-1. *Summary of the decision-making process for the siting, construction and operation of CLAB.*

Date	SKB	Authorities and Municipalities
1977 Nov.	Application submitted to the Government for the siting of CLAB at Forsmark, Simpevarp or Studsvik in accordance with the Building Act.	
1977 Nov.	Application submitted to the Government for permission to construct and operate CLAB in accordance with the Atomic Energy Act.	
1978		Östhammar, Nyköping and Oskarshamn municipalities approve siting.
1978		Final comments from county administrative boards and municipalities.
1978 Dec.		Government decides on the Simpevarp site in accordance with the Building Act.
1979 March	Application to the National Licensing Board for Environmental Protection.	
1979 July		Licence granted by the National Licensing Board for Environmental Protection in accordance with the Environment Protection Act.
1979 Aug.		Government decides to grant permit in accordance with the Atomic Energy Act.
1979 Oct.	Preliminary safety report (PSR) submitted to SKI and SSI.	
1983 Dec.	Final safety report (FSR) submitted to SKI and SSI.	
1985 May	Review of and supplements to the above-mentioned reports.	
1985 May	Application to SKI for operating licence.	
1985 June		SSI grants permission for nuclear trial operation from the standpoint of radiation protection.
1985 May		
1985 June		
		SKI decides that CLAB may be taken into operation.

The Government's decision to grant the permit in accordance with the Atomic Energy Act stipulated that SSI was to issue the special regulations which were required for radiation protection and SKI was to issue the required safety-related regulations. During the period of construction, SSI and SKI were informed of the design and construction work and of the results of the control programme. Comments and review statements were successively issued during this period. Shortly after SKI had granted the operating permit, SSI also approved the commissioning of SFR and stipulated conditions.

The permit granted by the Government carried certain conditions. One of these was that SKB, in connection with the start of construction work and subsequently as it progressed, would, in consultation with the county administrative board, SKI and SSI, inform the public and parties concerned of safety-related measures to prevent radioactive discharges from the facility. Through the new Act on Nuclear Activities, the task of the local safety committees was expanded to include the responsibility of providing information to the general public. Therefore, SKB found it suitable to carry out the consultation work, imposed by the Government's conditions, together with the local safety committee in the municipality as well as with SKI and SSI.

After the Government had granted the permit, four public information meetings were held. These meetings were arranged by the local safety committee of the municipality. An account of the work situation, issues concerning the safety of the repository and the authorities' role in connection with the construction work were dealt with at the meetings.

Once a year, SKB also invited the authorities and municipal representatives concerned to view the construction site, when they were informed about the status of the project and work on the Final Safety Report (FSR).

The county administrative board has previously held annual meetings to inform the public about "the environmental impact of operations at Forsmark nuclear power plant and certain issues relating to fishing". These meetings are held at the end of January and, since 1983, SKB has been invited in to the meetings to inform the public about the final repository.

SKI's operating permit for SFR in 1988 contained certain regulations relating to operating restrictions pending supplementary data. These data were presented by SKB in an in-depth safety assessment which was submitted to SKI in August 1991. In May 1992, SKI (and SSI) decided to lift the restrictions regarding the operation of the silo section of SFR after examining SKB's data.

SFR's operation is regularly controlled by the authorities, and every ten years, SKB is required to submit an updated safety assessment to SKI.

9.1.3 Siting of the Äspö Hard Rock Laboratory

As early as in R&D Programme 86, it was noted that a new underground laboratory should, in the first instance, be located in an area where the services and infrastructure necessary for the work already exist.

In the first instance, one of the nuclear power plant sites should be investigated. The most suitable was Simpevarp in the Oskarshamn municipality.

Investigations in the Simpevarp area were initiated during autumn 1986. On the basis of the results obtained, SKB made a decision regarding the principle of locating the laboratory on the southern part of the island of Äspö. The reasons for selecting this site were published in R&D Programme 89:

Table 9-2 *Summary of the decision-making process for the siting, construction and operation of SFR.*

Date	SKB	Authorities/Municipalities
1980-81	SKB investigates the siting of a repository for low- and intermediate-level waste. Potential sites at Forsmark, Oskarshamn and Studsvik are studied.	
1982 March	SKB submits a siting application in accordance with the Swedish Planning and Building Act (PBL), Atomic Energy Act and Environment Protection Act (ML).	
1982 June		SKI and SSI approve the siting of the repository (PBL-related matter).
1982 Sept.		The municipal council of Östhammar grants its approval.
1982 Oct.		The National Licensing Board for Environmental Protection holds a public meeting (ML-related matter).
1983 April		SKI grants its approval in accordance with the Atomic Energy Act (with conditions).
1983 June		Final statement from the municipality and county administrative board.
1983 June		The Government grants a siting permit with SKI's conditions attached.
1983 July		The National Licensing Board for Environmental Protection (KN) approves the initiation of siting in accordance with ML.
1983 Dec.		KN grants the permit and establishes the conditions for construction.
1987 July		KN holds a public meeting.
1987 Sept.		KN establishes the conditions for operation. An appeal is brought against the conditions by the Environmental Party and others.
1987 Oct.	Application for operating permit in accordance with the Act on Nuclear Activities (KTL).	
1988 March		SKI and SSI grant permission for the commissioning of the facility with certain restrictions, and stipulate regulations.
1988 April		The Government decides not to handle the appeal in accordance with ML.
1991 Aug.	SKB supplies an extended safety assessment report.	
1992 May		SKI nullifies certain conditions concerning operating restrictions.

It meets the requirement on undisturbed conditions in the bedrock and the groundwater. Locating the Hard Rock Laboratory on Äspö should ensure that other activities will not disturb the research during the time required for long-term experiments.

Äspö provides access, within a geographically limited area, to the different geological and hydrological conditions required for planned tests and their evaluation. The results of investigations of the bedrock on Äspö show a suitable variation between volumes of sound rock and fracture zones of varying character. The composition of the groundwater is representative of Swedish coastal rock and provides an opportunity for studies of prevailing conditions and changes in these conditions resulting from the construction work.

The proximity to the facilities at the Oskarshamn nuclear power plant on the Simpevarp peninsula minimizes the need for surface buildings. Service facilities and personnel that can be utilized for the activities are available nearby. The various facilities at the Oskarshamn nuclear power plant are also suitable for stationing of researchers, meetings etc. The fact that OKG owns the land in question facilitates the leasing of the necessary land.

R&D Programme 89 also made clear that the actual site of the Äspö Hard Rock Laboratory would not be considered as a site for the final repository. However, if suitable geological conditions were found in the vicinity, it could become one of the candidate sites which would be the object of a detailed characterization prior to the final siting of a deep repository.

While the Äspö Hard Rock Laboratory is certainly an underground facility, it is not really comparable to a deep repository for spent nuclear fuel, since no radiological activity will be carried out at the site. Neither is it a facility of the kind referred to in the Act concerning the Management of Natural Resources etc. which would be subject to compulsory review, although the Government can decide to review the Laboratory for other reasons as well. This could occur if the facility can be assumed to be of "considerable size or of an encroaching nature". In the Government's view, the Äspö Hard Rock Laboratory was such a facility and would thus be subject to review, in accordance with the NRL, since the Laboratory was to be located in an area which, in accordance with the NRL, receives special protection against property development companies which can tangibly diminish the area's natural and cultural value.

The following conditions were stipulated in the Government's decision:

- SKB shall, in consultation with the county administrative board and the municipality, prepare a plan for the practical use of any excavated rock which arises.
- Backfilled and excavated areas shall be dealt with in consultation with the county administrative board. Any changes to the environment which are not permanently needed for the activities to be carried out at the site shall be restored.

The design of the facility is further regulated by the Environment Protection Act, the Water Act, the Swedish Planning and Building Act and the Nature Conservation Act.

9.2 DISCUSSION, APPROACH AND PREPARATIONS OF THE AUTHORITIES ON THE SITING ISSUE

The issues surrounding the siting of the deep repository, and especially the decision-making process, have previously been discussed in connection with the review of R&D Programme 86 and R&D Programme 89 by external bodies. For further information on this subject, see /9-1, 9-2/ and the special Site Selection Report which was prepared by the National Board for Spent Nuclear Fuel (SKN) on behalf of the Government /9-3/.

In connection with SKB's establishment of the siting project, meetings were held with SKN, SKI and SSI to inform them of the general structure of the initial work. Information will be provided to these authorities (SKI, SSI) at regular intervals during the course of work.

The authorities are developing their own expertise and carrying out their own analyses of important, and in particular, geoscientific, technical and safety-related issues. For example, SKN has recently published three reports /9-4, 5, 6/ within a project called "Investigation into the Basis of Siting a Final Repository for Spent Nuclear Fuel". SKI is carrying out a comprehensive safety assessment project as a stage in the preparations for a safety review. Within the Dialog project, a simulation involving a fictitious application for the construction of a deep repository is being carried out to identify and discuss issues which can be considered important to treat in connection with future reviews of SKB's application. Besides the authorities, some municipal politicians and representatives for environmental organizations are also taking part in the Dialog project. In order to benefit from the results of the authorities' preparations, SKB is closely studying the views and conclusions which are being reported.

9.3 SELECTION OF SITES FOR DEEP REPOSITORIES IN OTHER COUNTRIES

Work on siting repositories for high-level and/or long-lived waste is in preparation or in progress in all countries with a major nuclear power programme. In some countries, the site to be the focus of investigations for the construction of a deep repository has already been selected. Figure 9-1 is a list of sites where underground repositories are currently located or where investigation and/or construction work is being conducted with the aim of finally disposing of nuclear waste, provided that the site is found to be suitable. In several countries, e.g. Finland, the process is already at the stage where a handful of sites are being investigated to ascertain their suitability for a deep repository, although none of them has yet been selected for more detailed investigation.

SKB has commissioned a survey of site selection practices in different countries /9-7/. A similar investigation has also been carried out by SKN /9-6/. Some of the conclusions reached by SKB from these studies are as follows:

The siting process is heavily dependent upon the existing conditions in each country, especially those relating to the procedures for review by the authorities and the political decision-making process. Thus, great caution must be exercised when applying conclusions drawn from one country to another.

If the focus of the siting work is flexible and pragmatic, starting from the fundamental criteria as regards safety, technology, environment, public opinion and local involvement, the possibilities of attaining good results are considerably greater than if detailed criteria and formal systems for, e.g. grading and screening sites, were used.

Information to and cooperation with the municipalities and authorities concerned is important.

Parallel detailed characterizations of several sites should be avoided. Instead, the investigations should be conducted sequentially, where the decision to continue or initiate investigations at a new site is taken on the basis of the results obtained.

Planned or existing underground repositories for the final disposal of nuclear waste

1 Waste Isolation Plant (WIPP), New Mexico, USA

Planned repository for long lived nuclear waste from the US military program. The waste is deposited underground in a salt formation at a depth of about 600 m. The application for the trial disposal of waste for 5 years, followed by evaluation and full-scale operation, is currently being examined by the authorities.

2 Yucca Mountain, Nevada, USA

Site selected by the US Department of Energy for study and evaluation work connected with a repository for high level waste. According to plans, the waste is to be deposited in volcanic rock (tuff), about 300 m underground but above groundwater level.

3 Gorleben, Germany

Extensive studies have been in progress since 1979 of a salt dome in Gorleben. Two shafts have reached the upper part of the salt dome at a depth of about 300 m. The repository is intended for all kinds of waste, including high level waste. The facility is planned to be taken into operation around 2010.

4 Asse, Germany

An abandoned salt mine where containers with low level and intermediate lewel waste have been deposited at a depth of about 300 m during 1967–1978. No futher deposits are planned. The repository is used for research and development purposes.

5 Konrad, Germany

An abandoned mine in sedimentary rock bearing iron ore, which is intended for use as a repository for low level waste at a depth of about 700 m. Licencing is in progress.

6 Sellafield, Great Britain

A site which is being studied for the possible siting of a final repository for long lived, non-high level waste, at a depth of about 900 m in volcanic rock. The site is adjacent to a large nuclear complex. Construction is planned to start in around 1996.

7 Mol, Belgium

An underground laboratory at a depth of about 250 m in a clay formation. The laboratory was constructed in 1983 to evaluate and demonstrate the technical feasibility and safety connected with the disposal of high level waste in clay formations.

8 SFR, Forsmark, Sweden

The Swedish final repository for low level waste. The repository is located at a depth of 60 m in crystalline bedrock. The repository has been in operation since 1988.

9 VLJ, Olkiluoto, Finland

The Finnish final repository for low level waste, located at a depth of 70 to 100 m in crystalline bedrock. The repository has been in operation since 1992.

Figure 9-1 *Sites where underground final repositories for nuclear waste are currently located or planned. All countries with a large nuclear waste program have planned to deposit spent fuel or high-level waste in geological formations.*

10 GEOSCIENTIFIC PRE-INVESTIGATIONS

The concept of pre-investigation covers studies (investigations and field measurements) which must be carried out to obtain the necessary data for the preparation of an application to carry out a detailed characterization of a site. The technical/socio-economic studies are discussed in Chapter 11. The plans concerning environmental impact statements and safety assessments are described in Chapter 12. The planning of a geoscientific pre-investigation programme is reported in this chapter.

10.1 GENERAL

Through the study site investigations, carried out at about 10 sites, the pre-investigations for the Äspö Hard Rock Laboratory, SFR and CLAB, and other geoscientific research projects, SKB has acquired extensive experience of geoscientific site investigations. In the light of this, a programme for the geoscientific pre-investigations will be prepared, so that the pre-investigation stage can be conducted in a rational manner, with high requirements being placed on a correct scientific approach and on quality. Experience from corresponding pre-investigations in other countries, e.g. Finland, will also be utilized.

Geoscientific pre-investigations will be carried out on at least two sites. Initially, the purpose of these investigations is to provide a closer identification of a potentially suitable site within a previously selected candidate area, e.g. a municipality. The investigations carried out at this site will then focus on the geoscientific characterization of the rock so as to determine whether the site is suitable for a deep repository. The investigations must satisfy the need for site-specific data which is required for safety assessment, construction feasibility analysis and design and engineering prior to the application for the detailed characterization permit in accordance with the Act concerning the Management of Natural Resources etc. This requires active cooperation both as regards planning and the evaluation of results. This process is illustrated in Figure 10-1, as interacting factors which must all function in phase with each other.

10.2 EXPERIENCE FROM SKB'S PREVIOUS SITE INVESTIGATIONS

Since 1977, SKB has pooled considerable resources into collecting data through different kinds of field measurements. The purpose of these field measurements has varied, from testing measurement methods or other special research and development projects, to different kinds of rock type-specific or site-specific investigations. Thus, some form of field measurement has been carried out at more than 15 sites in Sweden, see Figure 8-1. During the approximately 15 years which have passed since SKB's first field measurements, measurement methods have been considerably improved and refined as the investigation strategies have been developed and rationalized. Taken as a whole, this means that SKB and its external consultants have built up a considerable experience of site investigations.

SKB's previous site investigations were conducted as part of the KBS project. Initially, site investigations of varied scope were carried out between 1977-79 at five different sites in Sweden; Finnsjön and Forsmark in northern Uppland, Ävrö and Kråkemåla north of Oskarshamn, and Sternö near Karlshamn in Blekinge. These

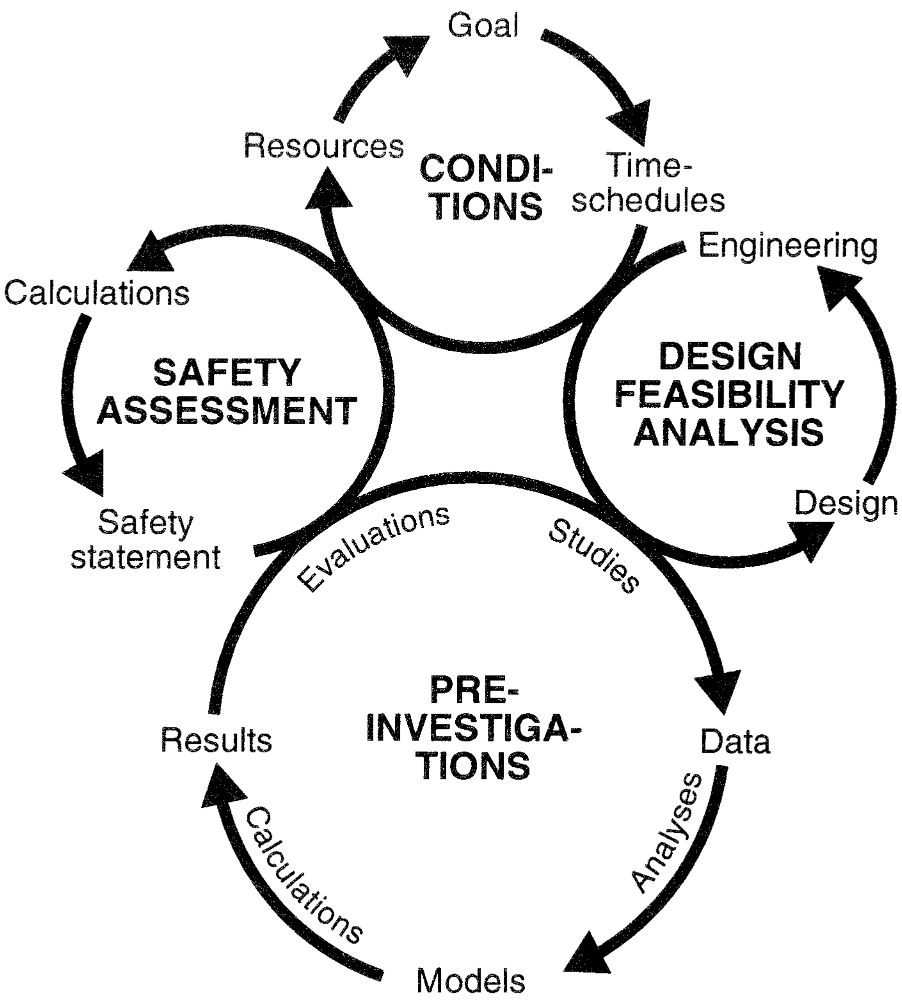


Figure 10-1 *Interaction between pre-investigations, safety assessments and construction feasibility analyses.*

study site investigations were carried out to collect basic data on Swedish crystalline bedrock, of a general as well as a site-specific nature, for use in the first safety assessments, KBS-1 and KBS-2. Geoscientific site investigations of this type and scope had previously not been carried out in Sweden, nor anywhere else in the world with regard to the crystalline bedrock. In general, knowledge, especially regarding borehole investigations at great depths, was very limited, which meant that this series of site investigations, in many respects, was carried out using techniques which were developed in parallel to, and within the framework of the KBS programme. This was, to a great extent, the case for the hydrogeological measurements whose development was described in SKB's R&D Programme 89.

In 1977, field research was initiated at the Stripa mine in Bergslagen. Iron ore mining had just been discontinued and SKB's work started off with an investigation of the geological and hydrogeological conditions in the mine and the nearby area. This investigation was based on old mine charts and other documents as well as on new field measurements. This work formed the basis of the 14-year period which made the Stripa mine into the centre of the first large international research project within the field of nuclear waste.

Considerable progress has been made within the Stripa project on developing characterization tools including instruments and methods as well as investigation strategies. One example of this is the borehole radar technique which was solely developed within this project and was found to be a very valuable instrument for identifying structures in the rock. The same is largely true for seismic borehole investigations, which were developed within this project with regard to a new type of measurement equipment as well as a new interpretation technique. In addition, important advances have been made at Stripa as regards understanding and being able to describe radionuclide transport in crystalline bedrock. Results and conclusions from the Stripa project are summarized in Chapter 13 of the main report and presented in detail in the final report "The Stripa Project. Summary of Results (1980–1992)".

During the 1980s, the Finnsjö area became an area where different types of method tests were carried out to develop and improve measurement methods and to verify their usefulness. Thus, different methods for hydraulic tests, tracer experiments and dilution probe measurements as well as a strategy for hydrochemical sampling were developed and tested. During the second half of the 1980s, a large study on the characteristics of a fracture zone was carried out /10-1/. The fracture zone project in Finnsjön showed the difficulty of locating horizontal or sub-horizontal fracture zones from the surface, even if they are of a significant size. The project provided knowledge of investigating large fracture zones, above all with regard to their hydraulic and hydrochemical properties. In addition, the effect of salt water on the groundwater flow could be studied. This involved the use of dilution probe measurements, a measurement method which was developed to determine the natural groundwater flow from in-situ measurements in boreholes. Two large-scale tracer experiments have also been carried out in the Finnsjön project – a radial converging tracer experiment /10-2/ and a dipol experiment. These experiments are now being used as test cases in the international model validation project, INTRAVAL /10-3/.

The study site investigations continued during the first half of the 1980s with the major effort being made during 1980–1983, when Fjällveden, north of Nyköping in Södermanland, Svartoberget near Voxnan in Hälsingland, Gideå near Husum in Ångermanland and Kamlunge north of Kalix in Norrbotten were investigated. A total area of 50 km2 was mapped and 163 holes were drilled and measured, almost simultaneously at all the sites. Besides stretching organizational skills to their limit, this project made large demands on materials and personnel, both in terms of quality and quantity /10-4/. The results of the investigations formed the basis of a new safety assessment, KBS-3, /10-5/.

The study site investigations which came to an end with Klipperås between 1982–1985, have yielded large quantities of site-specific measurement data. These data have been collected in SKB's database, GEOTAB.

The Äspö Hard Rock Laboratory project was initiated in autumn 1986. The goal included the testing and further development of investigation methods for bedrock with regard to the need for data which will arise for the future construction and licensing of a deep repository.

The pre-investigation stage of the Äspö Hard Rock Laboratory project was carried out in four years during the period 1986–1990. The investigations were conducted in stages, where each stage meant a gradual increase in the degree of detailed investigation on progressively smaller investigation areas. The pre-investigations have covered the development of instrumentation and methodology for hydraulic cross-hole tests /10-6/. These tests, carried out between two or more boreholes, have been found to be very useful in the development of the hydraulic structure model since hydraulic response provides a direct confirmation of direct contact along a hydraulic structure or via two or several such structures which are in contact with each other. In addition, methods have been developed for effective long-term measurement of variations in groundwater pressure and groundwater chemistry. The method of carrying out core drilling has been considerably improved and this has improved the success of hydraulic sampling. In addition, the method has created conditions for the cross-hole tests mentioned above and for long-term measurement of groundwater conditions. Large-scale pump tests over a long period of time have been carried out to simulate sinking from a shaft and to calibrate the numerical model. A radial converging tracer experiment was also carried out with radioactive tracers at the time of the pump experiment.

In addition, field investigations have been carried out in connection with several other geoscientific research and development projects. For example, the borehole radar method which was previously mentioned has been further developed as regards method and application. A detailed study of a fracture zone at Stripa has been carried out, where tomographical cross-hole measurements have been carried out to detect water-bearing parts of the zone in connection with the injection of salt water /10-7/. Tomographical cross-hole measurements using radar as the pre-investigation tool in underground constructions have also been tested in connection with a tunnel construction in Stockholm.

Experience from pre-investigations has also been gained from SKB's own waste storage facilities, CLAB and SFR. Especially from the design and construction of the latter, experience can be gained from the interplay between pre-investigations, construction feasibility analysis/design and safety assessment.

Through bilateral or multilateral international cooperation, SKB has had valuable opportunities to exchange knowledge and experience. The fact that countries working with similar repository concepts also place similar demands on the geosphere and on the pre-investigations which must provide data for safety assessment and construction planning is of great value. This is especially important as regards Sweden's cooperation with Finland, where it is not only a question of a similar repository concept but also of a bedrock which is part of the same crystalline basement – the Baltic Shield.

The contract research projects which are being conducted through SKB and through which the international exchange of knowledge is, in many cases, of a very concrete nature, can also be included in this international exchange. As far as measurement projects are concerned with, in many cases, the unique instrumentation which SKB has available, these projects increase the breadth of the combined knowledge of each area.

10.3 CONTENT OF THE PRE-INVESTIGATION PROGRAMME

A "Programme for Geoscientific Pre-investigations" is in the process of being prepared. The programme will be based on the collective knowledge and experience that exists at SKB within safety and performance assessment, handling technology, rock construction, geoscience, site investigations, measurement technology, data management etc. It will be based on the premise that the repository is designed according to the KBS-3 concept and that the repository site is located underneath a land mass. Results from projects such as SKB 91, the Äspö Hard Rock Laboratory, the Stripa project etc. will serve as a basis for defining which site-specific parameters are to be determined and how the investigations are to be carried out.

The programme will include the following points:

- Investigation strategy
- Technical investigation programme
- Synopsis report (describes goals and expected results)

- Data management
- Organization
- Administration
- Work and method descriptions
- Quality assurance programme
- Local information activities

Of these points, the first three deal with the contents of the pre-investigations, while the other points describe different kinds of tools for carrying out the programme.

10.3.1 Investigation strategy

The results from the pre-investigations shall provide a sufficiently large geoscientific database to enable the suitability of the conditions of the site for a deep repository to be determined. If this evaluation is positive, data must also be available to apply for and obtain a permit in accordance with the NRL for detailed characterizations. Data must also be available for a preliminary environmental impact statement. The geoscientific data will, at this stage, consist of general as well as site-specific data, collected from previous site investigations, supporting geoscientific R&D, general studies and pre-investigations.

The pre-investigations will be carried out in stages, which has proven effective for promoting an understanding of geological and hydrological structures and which facilitates coordination with the safety assessment and the construction feasibility analysis as well as the early planning and design work. Preliminarily, the pre-investigation stages will be as follows:

- Regional characterization
- Siting investigations
- Basic investigations
- Supplementary investigations

In order to further emphasize the importance of a goal-oriented pre-investigation programme, a synopsis report will be prepared. The purpose of this report is to present the goal of the different investigations and the kinds of results which will be obtained during the various stages of the pre-investigation programme.

10.3.2 Technical content of the pre-investigation programme

The following segment describes the technical content of the various stages of the programme. The idea is that all activities, measurements, investigations, data processing, analyses etc. shall be goal-oriented and yield data or results which have documented destinations.

Regional characterization

The purpose of the regional characterization is to obtain knowledge of large-scale geological and geohydrological conditions in the region surrounding the potential repository site. The investigations shall, among other things, provide data for boundary conditions to be used in calculations regarding groundwater flow and nuclide transport. The regional characterization shall also provide data for locating and describing discharge area(s) for the groundwater that passes by the repository and data for modelling the present and future biosphere.

The regional characterization is mainly based on existing bodies of data, maps, aerial photos, aerial geophysics, well data, earlier survey results etc. Depending upon the scope of the data, it may need to be supplemented. The field surveys foreseen are mainly geological mapping and aerial and ground geophysical surveys.

Siting investigations

The purpose of these investigations is to provide a deeper picture of the geological, hydrological and geohydrochemical conditions at a few sites within the candidate area (e.g. part of a municipality) that have been identified by the previous general studies. The data shall, together with other non-geological factors, serve as a basis for proceeding with subsequent investigation of one site per candidate area.

The field measurements will consist of surface investigations and borehole investigations of limited scope, preferably 100–200 m percussion-drilled boreholes and perhaps one or two deep cored boreholes.

Basic investigations

This stage is aimed at developing detailed geological and geohydrological models for the candidate site. The main body of basic data is collected during this stage, through surface measurements and borehole investigations. The boreholes are positioned and aimed so that the most important fracture zones are intersected and so that good representativeness of directionally dependent parameters such as fracture directions is obtained in the borehole investigations. One or more of the holes should reach a depth of about 1 000 m. Cross-hole measurements will be an important source of data in this stage.

This investigation stage will result in a conceptual model of the rock volume at the candidate site, with subject-specific descriptions of importance to safety assessment and construction feasibility analysis.

Supplementary investigations

This characterization stage is aimed at checking and reinforcing the conceptual model by increasing the degree of detail and filling in gaps where the body of data has been deficient.

The end result is used to compile a preliminary safety assessment and for construction feasibility analysis and design.

10.3.3 Data management

The pre-investigations will generate large quantities of data, from measurements as well as data from various stages in the chain of calculations, analyses and evaluations. Maintaining order in the flow and filing of data is an essential part of the pre-investigations. A good organization for data management will facilitate the technical work at the same time that it is a necessary condition for the quality assurance of the project.

As far as is practically suitable, data will be stored in a central database, SKB's current database GEOTAB or an equivalent. The aim of this is to ensure that this database does not only contain the final results but data from the various stages of evaluation. A 3-D CAD system will be connected to the database, which can be used as an evaluation tool and to illustrate the structure of the rock. The CAD system should also be used as a tool in the design work which should start as early as at the pre-investigation state.

10.3.4 Organization

An efficient organization is of utmost importance to the pre-investigations. The organization must include planning and steering to ensure that results from ongoing investigations are re-linked to the overall investigation programme, so that the project advances towards increased geoscientific understanding and so that needs from the standpoint of safety assessment and construction planning are fulfilled.

An efficient field measurement organization with technical support functions is essential to be able to carry out the programme.

Organizational planning and inventory-taking of resources will be carried out in connection with the setting up of the pre-investigation programme.

10.3.5 Quality assurance programme

To assure quality of results, it is essential that the methodology for the measurement, calculation, analysis etc. is documented. This also applies to technical documentation of instruments. Work and method descriptions as well as technical documentation will be prepared where they do not already exist.

Quality-assuring a pre-investigation of rock volume is not like quality-assuring a technical design. It is necessary to devise routines that are suitable for this type of activity so that the quality assurance is perceived as an aid in the work and not as a burden. Quality assurance of this type is being developed for the Äspö Hard Rock Laboratory and the experience gained will be used in the siting project.

The quality assurance programme will contain an "approval function" for programmes, work descriptions and a "control function" in connection with the execution of the programme. The "control function" will also contain routines for handling deviations from original plans, an aspect which is essential in order to benefit from new technique.

11 TECHNICAL AND SOCIO-ECONOMIC STUDIES

Aside from the purely geoscientific and safety-oriented investigations of a candidate site, a number of technical and societal aspects may have to be explored in order to determine whether a site is suitable and to describe the impact a deep repository may have on the environment and society in a broad sense.

One example of this is the transportation of encapsulated spent nuclear fuel and other material. A thorough investigation of each candidate site must be carried out to shed light on technical, safety-related, environmental and public opinion-related aspects of the transportation of canisters of spent nuclear fuel. This is necessary to provide a basis for:

- determining transportation routes and any onloading terminals,
- determining the need for new investment and cost estimates,
- future licensing of active shipments,
- the environmental impact statement, see Chapter 12.

In a similar way, other transportation activities, i.e. of backfill material will be identified.

Another example is the societal impact on a locality resulting from siting a deep repository there. Particularly if it is a question of a small town, this impact may be considerable. The establishment of what amounts to a local industry requires unusually long-range planning in this case. Pre-investigations, detailed characterizations, construction, operation and evaluation of a deep repository for demonstration deposition will, unless otherwise decided, be followed by an expansion to a full-scale repository for long-lived waste. This means that the activities will be pursued for more than 60 years. The overall effect of this will be an increase in both economic and social activities. This will create jobs and lead to some influx of personnel to the area. This, in turn will have an indirect effect on local small industries and business providing services. Disposal activities will also involve state-of-the-art environmental technology and the establishment of international contacts with a large number of visits to the facility. The fact that a deep repository is planned to be sited in a locality can affect the general perception and knowledge about the locality concerned.

The technical, economic and social aspects indicated above can have an impact on the local community and nearby residents. SKB's intention is to explore and clarify the actual positive and negative effects, as far as possible, in collaboration with the municipality and parties concerned. It will then be possible to discuss together, at an early stage, what can be done to avoid or minimize potentially negative consequences and to reinforce the positive ones.

Studies of the issues discussed above are best carried out when the candidate sites have been designated and cooperation has been established with the municipalities. Up until then, SKB plans to conduct studies of a more general nature concerning, e.g. transportation-related issues, employment effects and environmental impact.

12 ENVIRONMENTAL IMPACT STATEMENTS AND SAFETY ASSESSMENTS

Traditionally, and ever since the nuclear power plants were built, the nuclear power industry has evaluated the safety and possible environmental impact of their facilities and published these evaluations in special reports. Both in Sweden and abroad, preliminary and final safety reports (PSR, FSR respectively) have been prepared in conjunction with the building of nuclear power plants or other nuclear installations, such as SKB's final repository for reactor waste (SFR).

The concept of an environmental impact assessment or statement (MKB) is relatively new in Swedish legislation. Regulations requiring environmental impact statements were introduced in environmentally-related legislation in 1991.

An MKB aims at providing an improved basis for decision-making regarding the siting of industrial facilities. It shall be prepared by the applicant and submitted in connection with the application for the permit. According to the Act concerning the Management of Natural Resources, an environmental impact statement (in the act called an environmental impact assessment) shall "facilitate the joint assessment of the impact of a proposed installation, of an activity or various other measures on the environment, on public health and on the management of natural resources."

Recently the committee set up to review nuclear legislation proposed a regulation which states that "an environmental impact statement must be prepared concerning safety-related aspects".

The structure and content of an MKB is not defined by the legislation but is determined by the nature of the activity concerned and it is up to the authorities concerned to establish whether an MKB is adequate.

12.1 FUNDAMENTALS OF AN ENVIRONMENTAL IMPACT STATEMENT

The government white papers, bills and laws that deal with MKBs in Sweden place great importance on the fact that the environmental impact caused by an industrial installation shall be described in such a manner that it can be understood by the general public. This distinguishes it to some extent from the safety assessments mentioned above. An MKB also has a broader scope than a traditional radiological safety assessment, which is more to be regarded as one part (an important part) of the background material on which an MKB is based.

Certain emphasis is also placed on the investigation of the "zero alternative", i.e. the consequences to the environment if the repository is not realized. In the case of final disposal/deep disposal of spent nuclear waste, the zero alternative means continued storage in the central interim storage facility for spent nuclear waste (CLAB).

An interpretation of the applicable legislation and its supporting documents indicates that a series of factors must be taken into account when preparing an MKB, such as:

- impact on infrastructure, environment, outdoor life etc., from detailed characterization, construction/building, open operation, dismantling, sealing and closed operation of the repository, through the very fact of the existence of the activity and facility, surface area needed, increased traffic, appearance etc,

- discharges to the air and water of various substances, emissions from vehicles etc. in connection with the activities mentioned above,
- working environment for those who are professionally employed in the activities described above, including risk of accidents in conventional and radiological work,
- impact on adjacent catchment areas of construction work and draining of underground facilities.

12.2 PLANNED ENVIRONMENTAL IMPACT STATEMENTS AND SAFETY ASSESSMENTS

SKB plans to prepare a preliminary MKB at an early stage of the siting work. The purpose of this is that the MKB should serve as a basis for the discussions with the municipality, local population and regulatory authorities of the facility's environmental impact. In this way, SKB can obtain valuable viewpoints and have time to take them into account in the work with the formal permit applications. Table 12-1 presents and comments on the MKBs and safety assessments that will be prepared. For a more detailed discussion of the safety assessments, see Chapter 10 of the main report as well as the background report "Detailed R&D Programme 1993–1998".

Table 12-1 *Plan for environmental impact statements and detailed safety assessments*

Siting process	Environmental Impact Statement (MKB)	Detailed safety assessment
Stage 1 General studies, Feasibility studies, Pre-investigations	A preliminary MKB is prepared at an early stage with a general assessment of the environmental impact of the entire process (investigations, construction, operation, sealing, long-term effects).	The safety assessment in SKB-91 is supplemented by near-field analysis for the chosen alternative.
	An MKB is prepared in suport of an application for a permit to conduct detailed characterization (NRL).	Analyses of bedrock conditions are performed for each site in conjunction with execution of pre-investigations. A site-specific assessment of long-term safety is carried out and appended to the NRL application.
Stage 2 Detailed characterization	An updated MKB is prepared in support of an application for a siting permit (NRL) and a licence (KTL).	A preliminary safety report (PSR) based on the comprehensive data obtained during the detailed characterization and in connection with the planning of the facilities is compiled in support of an application for a licence under KTL.
Stage 3 Construction	Possible updating of existing MKB.	A final safety report (FSR) comprises support for an application for an operating permit under KTL.

13 INFORMATION AND LOCAL INVOLVEMENT

According to the law, the nuclear power utilities are obliged to take all measures required to safely handle and dispose of nuclear waste. In order to build the necessary facilities, the Swedish Nuclear Fuel and Waste Management Company, which in practice bears the responsibility, must gain society's confidence in the methods developed by the scientists. It is therefore important to spread knowledge within Swedish society about nuclear waste and its dangers, about the research being conducted and the solutions which have been found. Open and factual information is a prerequisite for the justified demands made by society on insight into this issue and for the democratic decision-making process.

It can be difficult to understand the scientist's way of working and the perspectives that broad scientific knowledge provides. The additional fact that the solutions are interdisciplinary, i.e. they cover several different fields of research, may make it difficult, even for specialists in different areas, to view proposed solutions in their entirety. Therefore, it is very important to disseminate information that is easy-to-grasp, which provides Swedish citizens with the possibility of placing radioactive waste in a reasonable perspective and which neither exaggerates or trivializes the issues concerned.

There are certain ethical and moral principles which steer the development of SKB's technology. The aim is that future generations should not inherit any burdens – environmental or financial. Therefore, SKB is planning disposal methods which do not require any future monitoring to ensure their safety. Our descendants will have the freedom of opting to monitor the repository. However, if the repository should be forgotten, this should not result in any negative consequences. This ethical argument has, to a great degree, contributed to the design of the disposal solutions. An important task of SKB's information activities is to also transfer this background to the technical solutions selected. Information can also help to minimize any anxiety which might arise due to ignorance about the waste and the proposed solutions.

13.1 NATIONWIDE INFORMATION

The goal of SKB's information activities is to broaden and deepen society's knowledge of:

- The radioactive waste: how much there is today, how much there will be in all and what dangers it poses.
- The system which SKB has built up and which is already taking care of all radioactive waste. (Transportation system, SFR, CLAB).
- The scope and thrust of the work on future deep repositories which SKB and others are pursuing, the underlying ethical principles and the extensive knowledge that now exists concerning the possibilities of isolating waste.

This information is being disseminated through:

- Broad distribution of publications and other material.
- Study visits to SKB's facilities, lectures and seminars.
- Trade fairs and various types of exhibitions.

In order to access different parts of Sweden, SKB has developed mobile exhibitions held in summer onboard M/S Sigyn, the ship normally used for transporting nuclear waste, and in purpose-built exhibition trailers. The exhibitions are manned by SKB's permanent staff, i.e. researchers, engineers, business administrators, information specialists etc. The purpose of this is threefold: the exhibition staff has a broad knowledge, visitors can meet the people who actually work on solving the waste problem and last, but not least, it gives SKB the chance to listen to "ordinary people" and to take note of the issues and factors they consider to be important.

13.2 LOCAL INFORMATION

People living in the vicinity of SKB's facilities – SFR, CLAB and the Hard Rock Laboratory – will be given information of a local nature. This will be accomplished in cooperation with the nuclear power plants in whose vicinity SKB's existing facilities are located.

When SKB starts investigating candidate sites for the construction of a deep repository for spent nuclear fuel, local inhabitants will be given information which, in addition to more general facts, will also include detailed descriptions of how a final repository could look and operate in their particular area.

The purpose of this information is to spread knowledge about waste management, understanding for the solutions found and to demonstrate the possibility of cooperation to achieve the solution that is best adapted to the area in question. The information will contain descriptions of how surface facility could be designed and how the need for an infrastructure, communication, labour and other necessities could be met. The stages in the scientific investigations on-site, SKB's proposal for handling the consultative process and the legal licensing process will also be described. The purpose of the information will be to provide answers to any questions a nearby resident of such a facility may have.

The information activities may take the form of local information offices, local newsletters to households, study groups, seminars and information meetings at schools and workplaces, organized study visits to the actual site under investigation and to SKB's existing facilities. The purpose of the information activities is also to provide feedback to SKB on the issues, views and factors that the local population consider to be important.

13.3 FORM OF LOCAL COOPERATION

SKB's aim is to design the facility and activities in cooperation with local interested parties to attain optimum results. This means that the surface facility, the transport routes and other technical issues can be discussed and adapted, to a certain extent, to the wishes of the local population. To reinforce local information and local influence, a local body should be set up at an early stage, composed in a manner similar to that of the local safety committees which, according to the proposal in the committee report on changes in the Act on Nuclear Activities, will play a part starting from the detailed characterization stage. (A local safety committee is appointed by the Government for a term of up to three years. A maximum of ten members are recommended by the municipality in which the facility is situated, while a maximum of three are recommended by nearby municipalities that are affected in one way or another). SKB will work to give such a body an opportunity to work with and gain insight into the issues which arise during the course of the siting process. The body can also compile facts and information for the public, authorities and institutions at the local level.

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