Technical Report

TR-01-03

Integrated account of method, site selection and programme prior to the site investigation phase

Svensk Kärnbränslehantering AB

December 2000

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SKB

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Preface

The purpose of the ongoing siting process is to find a site on which it is possible to build a deep repository for encapsulated spent nuclear fuel that will be safe in the long term. This report summarizes the material SKB has gathered as a basis for the decisions that need to be made in order for SKB to commence site investigations for a deep repository. SKB's plan is that the investigations, which include test drilling, shall be initiated in 2002.

The report contains the supplementary accounts which the Government requested in its decision on RD&D-Programme 98 regarding alternative methods, material for site selection, and programme for the site investigations.

FUD
Research, Development and Demonstration

SKB considers it urgent that the competent authorities and the Government clarify in connection with their critical review whether the background material we present here can serve as a basis for:

1. adhering to the KBS-3 method as the most suitable alternative for Sweden and thereby a fundamental premise for the work in the site investigation phase,
2. proceeding with investigations and consultations on the selected sites in the manner proposed by SKB.

After critical review by the regulatory authorities and the Government's decision, the concerned municipalities have to make a decision on whether or not to continue their participation in order that the nuclear waste programme can proceed to the next phase. We believe it is important to take this step in order to get on with implementing a safe disposal of the spent nuclear fuel.

Stockholm, December 2000

Swedish Nuclear Fuel and Waste Management Company

Peter Nygårds
President

Claes Thegerström
Executive Vice President
in charge of Siting

Reading instructions

The report presents SKB's method and site selection as well as a proposed programme for the next phase of the siting process. The background material in the form of SKB reports and other references is extensive. This report is therefore of a summarizing character. For access to the complete body of material, the reader is referred to the main references.

The report is divided into four parts:

Part I – Background which describes the need for waste management, what remains to be done in SKB's programme, and which laws and conditions govern the programme.

Part II – Method which contains an analysis of alternative strategies and systems for disposal of spent nuclear fuel. This part also includes an updated system analysis for the main alternative KBS-3 and summarizes SR 97, the most recent assessment of the long-term safety of the deep repository.

Part III – Site which summarizes and evaluates a large body of siting data and describes and justifies SKB's choice of sites for further investigations.

Part IV – Programme which describes the plans for SKB's activities and the EIA procedure in the site investigation phase.

An account of the consultation which SKB has carried out with concerned municipalities, county administrative boards and regulatory authorities is given in the Appendix.

Structure of this report

Integrated account of method, site selection and programme prior to the site investigation phase

Main references

Method
- Comparative system analysis
- Zero alternative
- International survey
- RD&D-programme for very deep boreholes
- KBS-3-method

Site
- SR 97
- Feasibility study reports
- Geoscientific background material

Programme
- Requirements and criteria
- Geoscientific site investigation programme

Content

Summary

In order to dispose of the spent nuclear fuel in a safe manner, SKB plans to site a deep repository and an encapsulation plant with associated canister fabrication and transportation system. After an integrated evaluation of feasibility studies and other material, SKB will proceed with investigations of the rock and studies regarding establishment of the deep disposal system in the municipality of Oskarshamn or in Northern Uppland. The plans also include further study of the prospects for a deep repository in the municipality of Nyköping.

In the municipality of Oskarshamn, SKB plans further studies of a siting of the deep repository at Simpevarp. There SKB wants to initiate site investigations with test drilling. For the encapsulation plant, SKB wants to continue studying a siting at CLAB.

CLAB
Central interim storage facility for spent nuclear fuel

In Northern Uppland, SKB plans to study two siting alternatives for the deep repository. One is Forsmark in the municipality of Östhammar, where SKB wants to initiate a site investigation with test drilling. The other is Tierp north/Skutskär, where SKB intends to start test drilling in an area north of Tierp. First, however, a suitable drilling area with possible transport solutions needs to be defined. This alternative requires the participation of the municipalities of both Tierp and Älvkarleby. A siting of the encapsulation plant in Northern Uppland will also be studied.

For the municipality of Nyköping, SKB plans to conduct a new safety assessment for the Fjällveden area, based on data from previous investigations as well as additional studies of how a deep repository could be arranged. SKB will thereby gather data from yet another geographic and geological region beyond those that are prioritized. No test drilling is planned in Nyköping.

The goal of the site investigation phase is to obtain all permits needed to build the planned facilities. It will take an estimated 7–8 years to assemble the requisite supporting material, carry out consultations, compile siting applications and have these applications reviewed by the appropriate authorities.

An analysis of conceivable alternatives for managing and disposing of spent nuclear fuel has confirmed that deep geological disposal according to the KBS-3 method has the best prospects of meeting all requirements. The alternative of putting off a decision until some future time (the zero alternative) does not appear tenable. The assessment of long-term safety shows that the prospects of building a safe deep repository in the Swedish bedrock are good. Independent Swedish and international review of the safety assessment confirm that the body of data in this respect is adequate for the siting process to proceed to the site investigation phase.

KBS
Nuclear Fuel Safety

A fuller summary is given below of the account given in this report of method as well as site selection and programme for the site investigation phase. The point of departure for the account is the review comments made by the regulatory authorities and the Government's decision regarding RD&D-Programme 98. In its decision, the Government stipulated conditions for SKB's continued research and development programme. The analysis of alternative system designs was to be supplemented, mainly with regard to the zero alternative and very deep boreholes. Furthermore, the Government decided that SKB shall submit an integrated evaluation of completed feasibility studies and other background material for selection of sites for site investigations and present a clear programme for site investigations.

Method

The KBS-3 method for final disposal of spent nuclear fuel was formally examined by regulatory authorities and the Government in the early 1980s and comprised a basis for the permits to commission the nuclear power plants Oskarshamn 3 and Forsmark 3. The scientific and technical basis for the method has been continuously developed and reported to the regulatory authorities and the Government every third year. At the same time, SKB has followed developments for other strategies and methods and reported its assessment of them. The authorities and the Government have approved the focus of the programme on deep geological disposal according to the KBS-3 method with parallel evaluation of alternative methods.

The survey in this report of different conceivable strategies and systems is aimed at providing an integrated account of the deliberations that have led to the choice of the KBS-3 method as the main alternative. Based on SKB's account and the comments received from its circulation for review, concerned authorities and the Government need to offer their view on the commencement of site investigations aimed at final disposal according to this method.

Is disposal in the bedrock the best strategy?

After interim storage in CLAB there are two possible main ways of dealing with the spent nuclear fuel, see Figure 1. One entails regarding the fuel as a resource for recovery of material for new nuclear fuel. To achieve this, the spent nuclear fuel must be reprocessed.

The other way is to treat the spent nuclear fuel as waste. Several strategies and systems have been proposed for this. Some conflict with international agreements, such as disposal in deep-sea sediment, or are unrealistically costly and insufficiently reliable, such as launching into space. Internationally speaking, deep geological disposal is by far the dominant alternative. Finland has chosen the KBS-3 method and designated a site for its final repository. However, no country has built a final repository for spent nuclear fuel yet.

A third possibility has been proposed, namely long-term supervised storage, in other words storing the waste under human supervision for hundreds or thousands of years.

Reprocessing
Chemical process for separating fissionable and long-lived radionuclides from spent nuclear fuel

Transmutation
Long-lived radionuclides are bombarded with neutrons and converted into short-lived or stable nuclides

Reprocessing and transmutation

Reprocessing is performed today in several countries in order to separate (partition) uranium and plutonium for reuse in new nuclear fuel. Plutonium, which makes a large contribution to the long-term radiotoxicity of spent nuclear fuel, is thereby converted (transmuted) to more short-lived radionuclides. Reprocessing produces a high-level waste of fission products and other long-lived nuclides. This waste requires similar final disposal as spent fuel. For economic and political reasons, reprocessing for recycling of uranium and plutonium into new nuclear fuel has been dismissed as an alternative in Sweden.

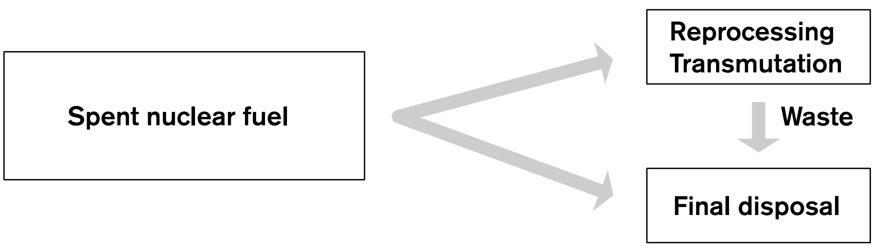


Figure 1. *Alternative ways of dealing with spent nuclear fuel.*

Research is being pursued internationally on more advanced methods for reprocessing and transmutation, where the spent fuel's content of long-lived nuclides is radically reduced. Realizing a practically functioning system will require extensive research and development plus a number of technically complicated facilities requiring very large investments. These facilities include new types of power-generating nuclear reactors, which are prohibited by law from being built in Sweden. It is not reasonable to expect that Sweden could develop and build such a system on its own. Even after advanced reprocessing and transmutation, a high-level waste containing long-lived radionuclides remains. Some form of final disposal of waste will be required in any case, similar to that needed for spent nuclear fuel.

Nuclear Activities Act
Act on Nuclear Activities
SFS 1984:3

Deep geological disposal

Geological disposal is a strategy that has the prospects of satisfying all requirements in international agreements and in Swedish law. The waste can be dealt with inside the country. Excessive burdens are not placed on future generations. Safety rests on multiple barriers. The impact of the radiation on man and the environment can be calculated and is found to be acceptable, both now and in the future.

SKB has found that final disposal deep down in the Swedish bedrock is the only realistic alternative if our generation is to take responsibility for the waste. This solution requires no measures on the part of future generations, but nor does it prevent them from retrieving the waste at their own risk. Post-closure retrieval is, however, an extensive operation on the same scale as deposition.

Supervised storage

In the circulation of SKB's research and development programme for review and comment, supervised storage has been proposed as a strategy for storing spent nuclear fuel for a long time, several thousand years. Experience of both wet and dry interim storage for a limited duration, up to several decades, exists in many countries, including Sweden. Environmental, safety and radiation protection requirements can be satisfied as long as human supervision and institutional controls are maintained, but not otherwise. SKB judges that the proposed strategy violates the requirement of not imposing excessive burdens on future generations.

What happens if we do nothing at all?

The so-called zero alternative entails postponing a final solution to the problem and continuing to store the spent nuclear fuel in CLAB. It is technically possible to extend storage in CLAB up to a couple of hundred years. This assumes, however, that continuous supervision and care of the facility is maintained. The zero alternative thus entails supervised storage in CLAB for an indefinite period of time, with the ethical and other problems mentioned above. Another serious problem is the risk of losing the competence that has been built up to deal with spent nuclear fuel in a long-term safe manner.

Is KBS-3 the most suitable method for geological disposal?

In the survey of different possibilities for achieving a deep geological disposal, four different alternatives have been studied: KBS-3, Very Long Holes, WP-Cave and Very Deep Holes, see Figure 2.

The primary function of a KBS-3 repository is to **isolate** the spent nuclear fuel. Secondarily, if the isolation should for any reason fail in any respect, the repository is supposed to **retard** the release of radioactive substances. The fuel is enclosed in corrosion-resistant copper canisters and deposited at a depth of about 500 metres, where stable mechanical and chemical conditions prevail. The canisters are surrounded by a layer of bentonite clay that constitutes a buffer in connection with minor rock movements and prevents corrosive substances from reaching the canister. The clay also effective absorbs radionuclides that are released if the canister is damaged.

Bentonite
Soft clay that swells on uptake of water

A repository in Very Long Holes is in most respects equivalent to the KBS-3 method, but is judged to have poorer prospects of satisfying the safety requirements during the construction and operating phases. WP-Cave is associated with difficulties in demonstrating long-term safety.

Very Deep Holes entails depositing encapsulated fuel in boreholes with a depth of approximately four kilometres. At this depth, the groundwater flux is very low. The idea is that the time needed for the groundwater to transport any radionuclides from the waste to the surface is so long that they will have decayed to harmless levels before reaching the ground surface. In its decision regarding RD&D-Programme 98, the Government stipulated as a condition for SKB's continued research and development activities that SKB shall describe the thrust and scope of the RD&D-Programme that is needed for a comparison of the Very Deep Holes alternative with the KBS-3 method, based on equivalent data.

The most important safety function of a repository based on Very Deep Holes is the retardation achieved by the rock and the great disposal depth. High rock stresses and high salinities in the groundwater at great depth mean that it is not possible in a safety assessment to assume with any great reliability that the canister and the buffer will remain intact in the long term. This means it is not possible to count on any long-term containment of the waste.

Possible advantages with a repository based on Very Deep Holes is that the risk of human intrusion and the impact of climate change are less at great depth. Among the difficulties are the fact that the basic technology for achieving deep boreholes with the dimensions in question is lacking, and that knowledge of conditions at great depths is very limited. The latter problem makes an evaluation of the safety of the system more difficult. SKB further deems the possibilities for monitoring deposition conditions and operational reliability to be worse than for the KBS-3 method.

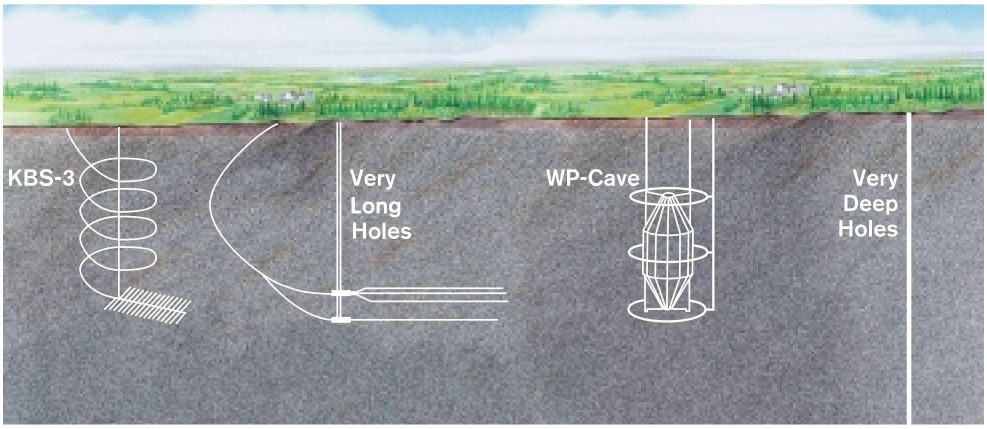


Figure 2. *Alternative systems for geological final disposal.*

In a recently completed study, SKB calculated that it would take about 30 years and cost SEK four billion to reach a level of knowledge of the alternative Very Deep Holes that makes it possible to carry out a safety assessment of the same quality as the safety assessment for the KBS-3 method. The comparative system analysis shows that there is no evidence that disposal in Very Deep Holes, even if it can be proven to meet all requirements, would enhance safety compared with a KBS-3 repository. Moreover, the estimated cost is considerably higher. For these reasons, SKB does not plan to carry out the RD&D programme for Very Deep Holes, but will instead concentrate its resources on building a repository based on the KBS-3 method in a relatively near future.

Is the deep repository safe?

To ensure safety during the operation of the facilities, we can apply established principles and experience from existing facilities in Sweden and abroad. Radiation doses to personnel and the environs are expected to be low from all steps in the process.

SKB's assessment of long-term safety, SR 97, shows that the prospects of building a safe deep repository for spent nuclear fuel in Swedish granitic bedrock are good.

During 2000, SR 97 was subjected to critical review by SKI and SSI and an international review organized by the OECD/NEA on behalf of SKI. An important conclusion in SKI's and SSI's review as regards the choice of method is that: "No circumstances have emerged in SR 97 to indicate that geological final disposal in accordance with SKB's method has any serious drawbacks in relation to the requirements made by the regulatory authorities on safety and radiation protection."

SKI
Statens Kärnkraft-inspektion (Swedish Nuclear Power Inspectorate)

SSI
Statens Strålskydds-institut (National Radiation Protection Institute)

OECD
Organization for Economic Cooperation and Development

NEA
Nuclear Energy Agency

In their summary, SKI and SSI further conclude "that parts of the methodology in SR 97 need to be further developed and defined in preparation for the site selection process." The authorities also believe that "the KBS-3 method is a good basis for SKB's upcoming site investigations and continued development of the engineered barriers."

The international expert group concludes: "No important questions have been identified that need to be answered before proceeding with the investigation of potential sites. Many observations and recommendations have been made which SKB and the safety authorities may want to take into account in their future development of Sweden's programme for final disposal of spent nuclear fuel."

SKB finds that the review of SR 97 provides support for our most important judgements: Firstly, that the knowledge base and methodology for the safety assessment satisfy the requirements made in conjunction with the site investigations, and secondly that the prospects of building a safety KBS-3 repository in Swedish bedrock are good.

Sites for site investigations

The siting process has now reached the conclusion of the feasibility study phase. The next phase, the site investigation phase, is aimed at gathering the data needed to site the deep repository and the encapsulation plant with associated support functions. Siting of the deep repository requires geoscientific investigations with test drilling on selected sites and more in-depth local studies for establishment of the entire deep disposal system. In SKB's opinion, a concrete body of data now exists with the breadth and the quality required to commence site investigations. In our opinion, there is also sufficient public interest in the nuclear waste issue and support for SKB's programme to make this continuation possible and warranted.

Deep disposal system
- CLAB
- Encapsulation plant
- Canister factory
- Deep repository
- Transportation system

Is the selection pool sufficient?

Feasibility studies have been conducted in eight municipalities. In two of these municipalities, Storuman and Malå, feasibility studies were followed by referendums in 1995 and 1997, respectively, on the question of further participation in the siting process for the deep repository. In both cases, the referendums resulted in a rejection of further participation.

Selection pool
- 3 geographic regions
- 4 geological environments
- 6 municipalities
- 8 siting alternatives

The other six municipalities – Hultsfred, Oskarshamn, Nyköping, Tierp, Älvkarleby and Östhammar – now comprise the selection pool from which SKB will select sites for further investigations, see Figure 3. Areas where the bedrock is judged to be potentially suitable for a deep repository have been found in all municipalities except Älvkarleby. The feasibility studies have revealed good potential when it comes to the technical and environmental aspects as well. The selection pool comprises eight different siting alternatives representing three different regions in the country with four different geological environments, and includes alternatives with different prospects for establishing a deep repository. Altogether, SKB believes that this pool provides sufficiently many promising alternatives for proceeding with the siting work.

At how many sites should site investigations be conducted?

SKB's ultimate goal is to build a deep repository within a reasonable time on a site where the safety requirements can be satisfied. The selection of sites for site investigations will be made among the eight siting alternatives that have been arrived at by the feasibility studies. For all alternatives, questions remain that must be answered before it is possible to finally decide that all requirements on a siting can be satisfied, and that the community's support can be obtained. Viewed from SKB's perspective, this involves a risk that must be evaluated and managed.

In principle, the more sites that are investigated, the greater is the possibility that at least one of them will ultimately satisfy the requirements. Investigations on more sites mean, on the other hand, that the site investigation phase requires more resources and takes longer time. Moreover, the engagement of politicians

Municipalities of Östhammar, Tierp and Älvkarleby
- Forsmark
- Hargshamn
- Tierp north/Skutskär

Municipality of Nyköping
- Studsvik/Björksund
- Skavsta/Fjällveden

Municipalities of Oskarshamn and Hultsfred
- Simpevarp
- Oskarshamn south
- Hultsfred east

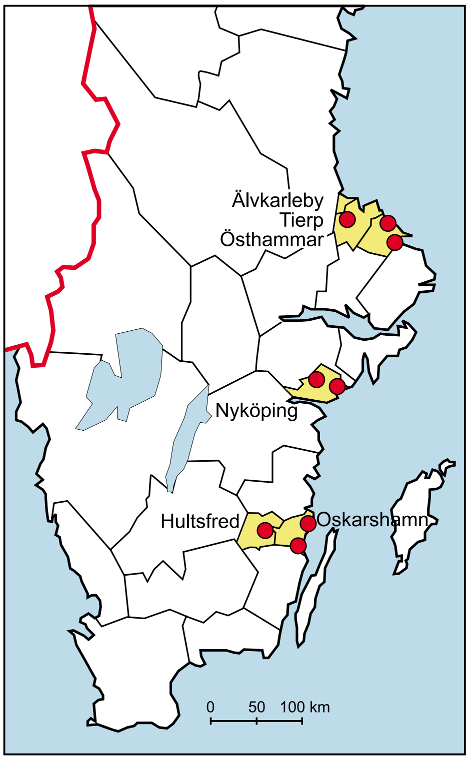


Figure 3. *The feasibility studies have resulted in eight siting alternatives for the deep repository. These comprise the selection pool for the choice of sites for site investigations.*

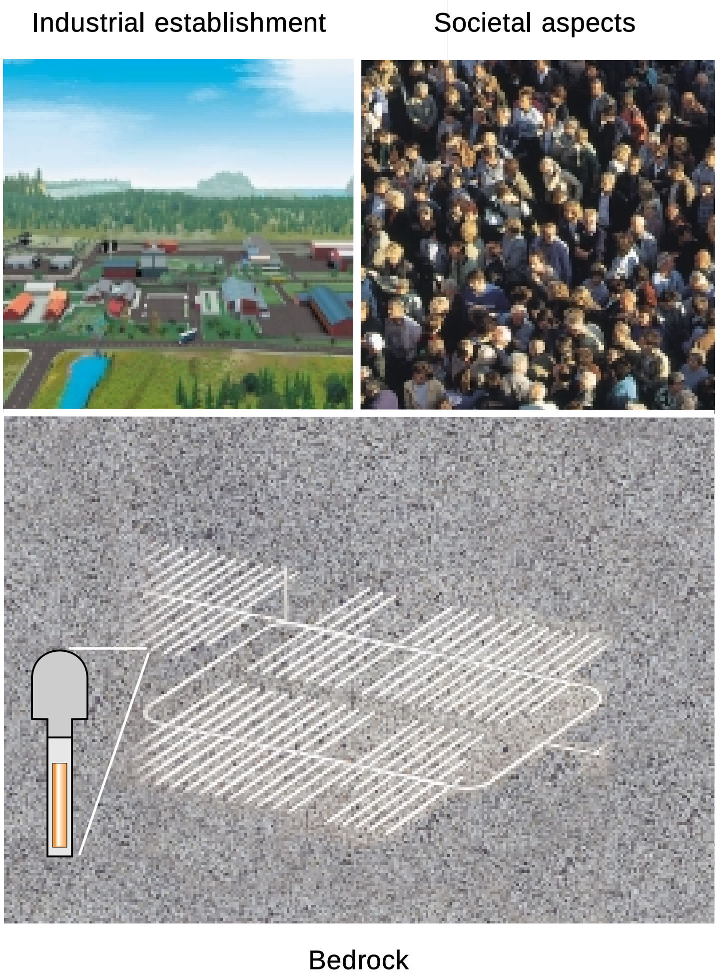
and the public is required in more municipalities during a longer period of time. This can be difficult to maintain, since the likelihood of any particular municipality being chosen decreases as the number of alternatives that are investigated increases. Furthermore, since the siting of the deep repository inevitably causes concern and raises hopes, these aspects must also be taken into account.

SKB's ambition is that the programme for the site investigation phase should be clear and robust. At the same time, the programme should have some flexibility so that changed conditions and negative test drilling results can be handled without jeopardizing the ultimate goal.

Determining the number of sites involves a risk assessment of many mutually incomparable factors and can thus not be done strictly scientifically. SKB must determine what is reasonable with respect to the ultimate goal and an evaluation of the uncertainties associated with the siting alternatives.

How does SKB evaluate the selection pool?

SKB has evaluated the eight alternatives with respect to requirements and preferences that can be assessed today as regards the bedrock, the industrial establishment and the societal aspects. The evaluations have been focused on the properties or conditions that are of importance for selection at this stage.



Bedrock

- All alternatives in the selection pool meet the safety requirements that can be checked now.
- The alternatives cannot be ranked in terms of safety based on what is known about the bedrock today.
- Test drilling is required to verify whether the bedrock satisfies the safety requirements. There is a risk that test drilling will reveal such conditions that a site must be abandoned.

Industrial establishment

- Simpevarp and Forsmark stand out as particularly suitable with respect to industrial establishment.
- There are good establishment prospects for several other siting alternatives, but the uncertainties are great, due for example to the need for overland transport of spent nuclear fuel and/or development of new land areas for industrial purposes.

Societal aspects

- The prospects of gaining public confidence and support for the deep repository project are difficult to assess and may change.
- It should be possible to gain public confidence and support in most municipalities, but the prospects are deemed to be particularly good for a siting at Simpevarp or Forsmark, providing that the bedrock there satisfies the safety requirements.

Which sites does SKB prefer?

SKB notes that Forsmark and Simpevarp have clear advantages from an establishment and societal viewpoint. These alternatives offer particularly good prospects for establishing and operating the deep repository's facilities and transportation system with small and acceptable environmental consequences. All in all they are judged to provide the best possibilities for satisfying the Environmental Code's requirement on "least possible intrusion and detriment." They have a good prognosis when it comes to the bedrock as well. With these advantages, it is difficult to see any reason why not to proceed with the Forsmark and Simpevarp alternatives. SKB's conclusion is thus that they must be included in the next phase.

In order for the programme to be robust, SKB deems that the continued siting studies should include more alternatives than the two mentioned above. The next phase should therefore include studies of alternatives that have good prospects, but are different from Forsmark and Simpevarp. Additional sites should mainly represent other geological conditions and be located in other municipalities.

Of the siting alternatives, Tierp north/Skutskär and Skavsta/Fjällveden can contribute towards broadening the geological range of alternatives. These sites should therefore be studied further, in SKB's opinion. Tierp north, together with Skutskär, offers good industrial establishment possibilities. SKB judges this alternative to be fully realistic from all aspects. There is a greater degree of uncertainty for Skavsta/Fjällveden with regard to feasibility.

Other siting alternatives do not offer any obvious advantages from the geological breadth aspect. However, there is not good reason at this point to either dismiss or commence site investigations for any additional alternative. Hargshamn is the leading alternative if it should not be possible to commence site investigations in Forsmark or if the investigations show that the bedrock does not meet the requirements. Similarly, Oskarshamn south and Hultsfred constitute possible alternatives to Simpevarp.

SKB's opinion is that a choice of Forsmark, Simpevarp and Tierp north for test drilling and further study, along with additional studies of the prospects for the Skavsta/Fjällveden alternative, offers a reasonable balance between the preference of a robust programme on the one hand and a reasonable level of cost and effort on the part of society on the other.

Against the background of the above evaluations and the current state of knowledge, SKB thereby prioritizes site investigations with test drilling at the following three sites:

- Forsmark in the municipality of Östhammar. The priority area is well-defined and it should be possible to commence site investigations with test drilling shortly after a decision to proceed.
- Simpevarp in the municipality of Oskarshamn. Large areas with potentially suitable bedrock exist west of Simpevarp, but the area nearest the nuclear power plant is prioritized. It should be possible to commence site investigations with test drilling shortly after a decision to proceed.
- Tierp north/Skutskär. The priority area north of Tierp is relatively large, so that initial efforts must be focused on defining a priority subarea for continued investigations and studying a suitable layout of the deep repository's surface facility and transportation system. After that, SKB intends to initiate test drilling within the priority subarea. This alternative requires the continued participation of the municipalities of both Tierp and Älvkarleby.

The greatest uncertainties for Skavsta/Fjällveden in the municipality of Nyköping are associated with industrial establishment and transportation. SKB therefore plans to proceed primarily with studies of these questions in order to clarify the feasibility of the alternative. As regards the bedrock in the area of interest, data are already available from repository depth. SKB intends to utilize these data to conduct a new safety assessment with the modern methodology used in the SR 97 safety assessment. Test drilling in Nyköping will only be considered if the first three alternatives mentioned above fail to live up to expectations.

In Hultsfred, SKB plans to conduct a study during the coming year in collaboration with the municipality of consequences and opportunities for the municipality associated with an establishment of an encapsulation plant and a deep repository in Oskarshamn. Site investigations are not currently being planned in the municipality of Hultsfred.

If any other alternatives should be found to be of interest, a discussion will be held with the concerned municipality and the regulatory authorities. Before any investigations are started on a new site, a clear decision must be obtained from the municipality supporting such a change in the programme.

SKB's process of selection and planning for the site investigation phase entails conducting continued investigations or studies for conceivable deep repository sites in the different geological provinces or geographical regions that are included in the selection pool. In this way, the results from the site that is ultimately chosen will be able to be compared with other alternatives in keeping with the provisions of the Environmental Code. Municipalities, concerned members of the public, authorities, the Government and the Environmental Court will not have to render their judgement on a possible siting application for the deep repository for another 7–8 years. Up to then, studies and investigations will be conducted of the bedrock, the technology, the environment and the societal aspects in order to compile the body of data that is needed to make a final judgement of the siting prospects.

Environmental Code
SFS 1998:808

A prerequisite for commencing the site investigations is that the concerned municipalities adopt a positive stand. Based on the experience we have from the feasibility studies, we believe that there are good prospects on this point as well. But the municipalities themselves will make the final decision.

Programme for the site investigation phase

What is included in the programme?

SKB's goal for the site investigation phase is to obtain the permits that are needed to site and build the deep repository and the encapsulation plant. For the deep repository, detailed characterization will then be able to be commenced on the selected site and the repository built for an initial demonstration deposition of 200–400 canisters.

The primary task for SKB during the coming years is to assemble the necessary supporting material for the applications, carry out consultations and prepare environmental impact statements in compliance with the requirements of the law. Permit or permissibility review takes place primarily under the Nuclear Activities Act, the Environmental Code and the Planning and Building Act.

For the deep repository, investigations of the rock are required to determine whether it is possible to build the repository on one of the candidate sites and to conduct a safety assessment. It is these investigations that have given the site investigation phase its name, since they dominate the activities during this phase. The investigations of the rock also serve as a basis for configuration of the underground portions of the deep repository. Another important part of the work is to study and formulate proposals for the local design of facilities and transportation systems. The impact of the deep repository on the environment and the community will be studied. In parallel, consultations will be held with the municipality, the county administrative board and the public, as well as organizations that can be assumed to be affected, in accordance with the requirements and intentions of the Environmental Code. When the study results have been compiled, SKB will submit permit applications for the encapsulation plant and the deep repository.

The site investigations are divided into two main phases. **Initial site investigations** are performed to identify the site within a specified area that is deemed to be most suitable for a deep repository and to determine whether the feasibility study's judgement of the suitability of the area holds up in the light of in-depth data. They are expected to take 1.5–2 years. If the assessment still stands up, **complete site investigations** follow for a duration of 3.5–4 years. The purpose of the complete site investigations is to gather the material that is required to select one of the sites as the main alternative and to apply for a permit for siting of the deep repository.

Programmes for the work in Northern Uppland, Oskarshamn and Nyköping during the site investigation phase will be prepared during the first half of 2001. The programmes will be designed with respect to the state of knowledge and specific questions for each site. They also need to take into account the viewpoints of the municipality, landowners and nearby residents, as well as nature conservation and other interests. The programme for Nyköping includes studies but not site investigations with test drilling.

The programme for research, technical development and demonstration will continue in parallel with the site-specific work. The body of knowledge will be augmented and safety assessment methodology will be refined. The work at the Äspö HRL and the Canister Laboratory on development and full-scale testing of deposition methods and encapsulation technology will continue, while international development of alternative strategies and systems will be kept track of.

Northern Uppland

The purpose of the programme is to gather material for a siting of the deep repository in Northern Uppland. The possibility of locating the encapsulation plant and the canister factory there will also be studied. Site investigations will

SFR
Final repository for radioactive operational waste

***Figure 4.** Photomontage of proposed positioning of the above-ground portion of the deep repository at SFR. The area of interest for site investigations is shown in the background.*
Photo Göran Hansson/N

be commenced in the vicinity of the Forsmark NPP. If the results here are positive, SKB intends to gather a complete body of material for a siting of the deep repository at Forsmark, see Figure 4. The area in Forsmark being considered for site investigations is relatively small and geologically clearly demarcated. This means that the investigations will start in a situation where a site is already identified. Test drilling should therefore be able to start relatively soon after a decision has been made on site investigations.

The inland alternative in Tierp comprises a large area, about 60 square kilometres, which means that initial efforts will be focused on defining a more limited subarea for site investigations and studying a suitable positioning of the repository's above-ground facility as well as suitable transport solutions. SKB then intends to initiate test drilling within this subarea. Figure 5 shows the location of the area in relation to urban centres and infrastructure.

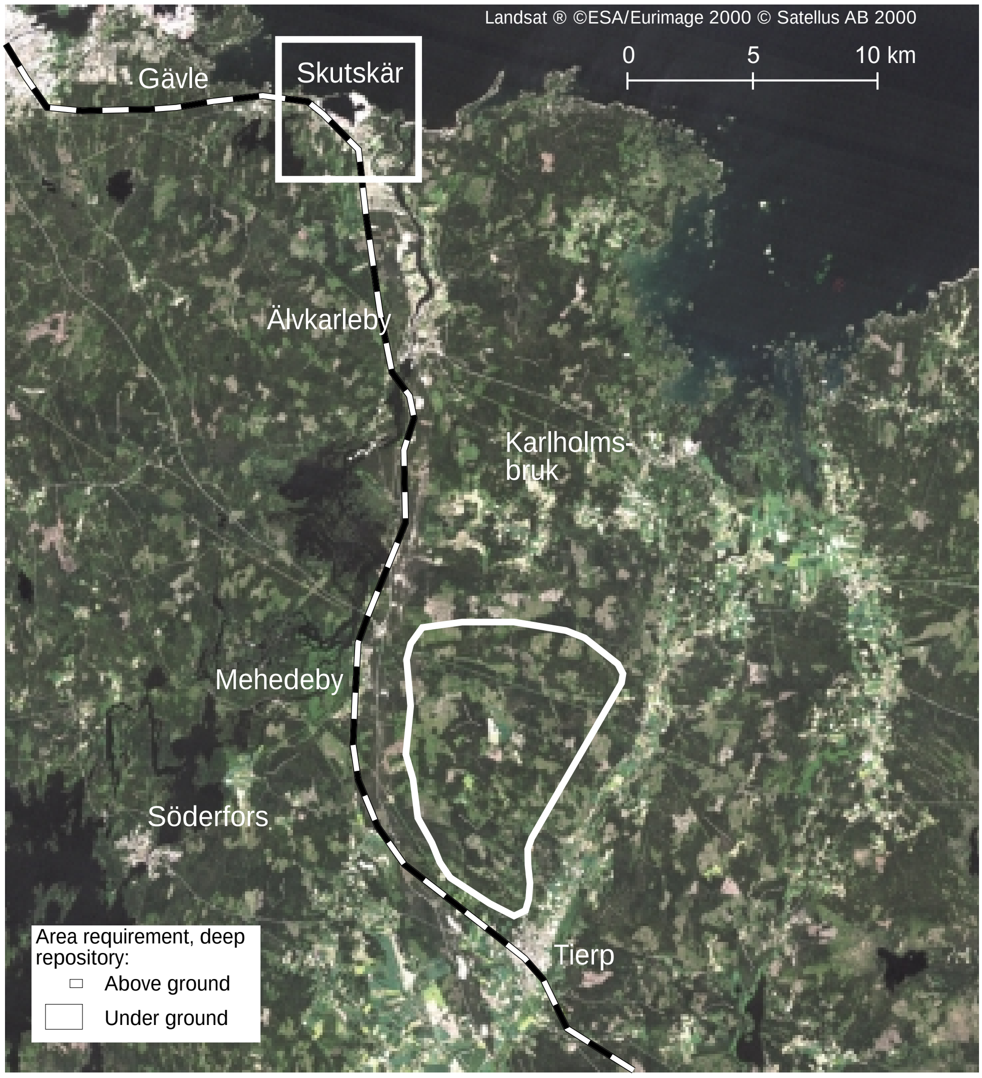


Figure 5. *Satellite image showing the harbour in Skutskär and the area in the municipality of Tierp that is of interest for site investigations.*

***Figure 6.** Photomontage of proposed positioning of the above-ground portion of the deep repository at Simpevarp. The area of interest for site investigations, besides the Simpevarp Peninsula itself, is shown in the background.*

Oskarshamn

The purpose of the programme for Oskarshamn is to gather material for a complete deep disposal system in the municipality. The main alternative for the deep repository is to locate the above-ground facilities on the Simpevarp Peninsula, with the underground facility as close as possible taking rock conditions into consideration. Figure 6 shows the Simpevarp Peninsula with the harbour, the nuclear power plant, CLAB and where the deep repository's industrial facility can be positioned.

Site investigations will be commenced in the area west of Simpevarp for the purpose of defining a site for complete site investigations. SKB also intends to investigate the Simpevarp Peninsula itself, even though it is not prioritized from a geological viewpoint. A siting there would entail many advantages from an establishment viewpoint, and SKB therefore finds in-depth investigations of the bedrock on the peninsula warranted.

In the main alternative, the encapsulation plant is located immediately adjacent to CLAB. Canister fabrication in the municipality or region will also be studied.

Nyköping

The primary purpose of the programme in Nyköping is to study the uncertainties associated with the industrial establishment, transport questions and societal support for various alternative solutions. The proposal for a siting of the deep repository at Skavsta/Fjällveden, see Figure 7, emerged at a late stage of the feasibility study and has not been examined as well as other siting alternatives. SKB intends to continue to study the feasibility of this alternative and to try to clarify whether societal support may be forthcoming.

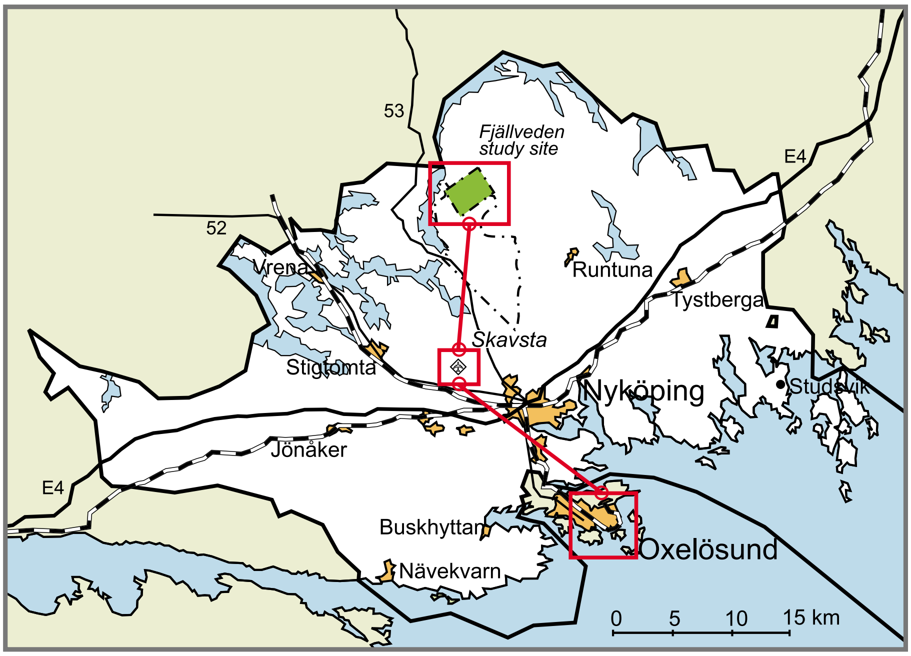


Figure 7. *Map with the localities where facilities may need to be built if the deep repository were to be sited in accordance with the Skavsta/Fjällveden alternative.*

Questions that need to be studied are how transport is to be arranged, the rock engineering prospects of building a long connecting tunnel between Skavsta and Fjällveden, and the design of the operating area that should be established in the Fjällveden area. The programme also includes performing a safety assessment with modern methods based on existing data from Fjällveden.

What happens now?

According to the Government decision on RD&D-Programme 98, the Swedish Nuclear Power Inspectorate will review this supplementary account in a manner similar to the way it reviews a regular RD&D programme, which entails e.g. extensive circulation for comment. An important element in this is the public hearings which SKI plans to hold as a part of its reviewing procedure. SKB will follow the circulation-for-comment process and its results. We will also continue the preparations for the site investigation phase.

In early 2001, SKB will open discussions with the concerned municipalities regarding what further information they may need to arrive at a decision on whether they wish to participate in the continued programme. Provided that the material now being presented can be processed by the regulatory authorities and the Government in keeping with the stipulated timetable and with a positive outcome, it is SKB's opinion that the municipalities should be able to arrive at a decision on the programmes by the end of 2001.

In conjunction with the transition to the site investigation phase, SKB will submit a formal notification pursuant to the Environmental Code to the concerned county administrative boards. This means that so-called extended consultation with environmental impact assessment can be commenced after the county administrative board's processing of the matter. This means that SKB will consult with concerned parties regarding the siting, design and environmental impact of the deep repository, the scope of the activities and the form and content of the environmental impact statement in accordance with the provisions of the Environmental Code.

Part I - Background

1 Waste

Operation of the nuclear power plants gives rise to radioactive waste, which can be divided into different categories according to the radioactive substances (radionuclides) contained in the waste, their life and activity level.

With reference to requirements on management and final disposal, the Swedish waste is divided into three main categories. The first is short-lived low- and intermediate-level waste. This category includes spent components, filters etc. from operation, maintenance and decommissioning of the nuclear power plants. The second category consists of high-level waste in the form of spent nuclear fuel. It comprises a smaller fraction of the volume, but contains most of both the short- and long-lived radionuclides. The third main category, long-lived low- and intermediate-level waste, includes e.g. spent components from the reactor core.

The spent nuclear fuel is hazardous (radiotoxic) for a very long time, and imposes special demands on management and disposal. The goal of its management is to minimize the risks by isolating the fuel from man and the environment as long as it is hazardous.

1.1 Where does the waste come from?

The nuclear power plants (NPPs) in Barsebäck, Forsmark, Oskarshamn and Ringhals, which were put into commercial service during the period 1972–85, produce approximately half of Sweden's electric power. Reactor operation gives rise to spent nuclear fuel. When the plants have been taken out of service, additional waste arises in conjunction with their decommissioning.

Radioactive waste was also generated during the research and development phase that preceded commercial nuclear power generation, mainly at the plants in Studsvik outside of Nyköping. Radioactive waste is still generated there today, for example at the test and research reactor R2. Fabrication of fresh nuclear fuel at the factory in Västerås (now owned by Westinghouse Atom AB) produces small quantities of nuclear waste.

The radioactive waste from nuclear installations, see Figure 1-1, is designated *nuclear waste* in the Nuclear Activities Act. However, in the sense of the law, nuclear fuel does not become nuclear waste until it has been emplaced in a final repository. Before that it is classified as *nuclear material* due to its content of fissionable substances. Since the main strategy in Sweden has long been to dispose of the spent nuclear fuel in a final repository, however, spent nuclear fuel is usually also included in the category "nuclear waste", as it is in this report.

Nuclear Activities Act

Act on Nuclear Activities
SFS 1984:3

Nuclear material

Material that can be used for extraction of nuclear energy

Radioactive substances that give rise to radioactive waste are used elsewhere in society as well – in industry, research and medical care. However, by far most of all radioactive waste arising in Sweden derives from the nuclear power plants.

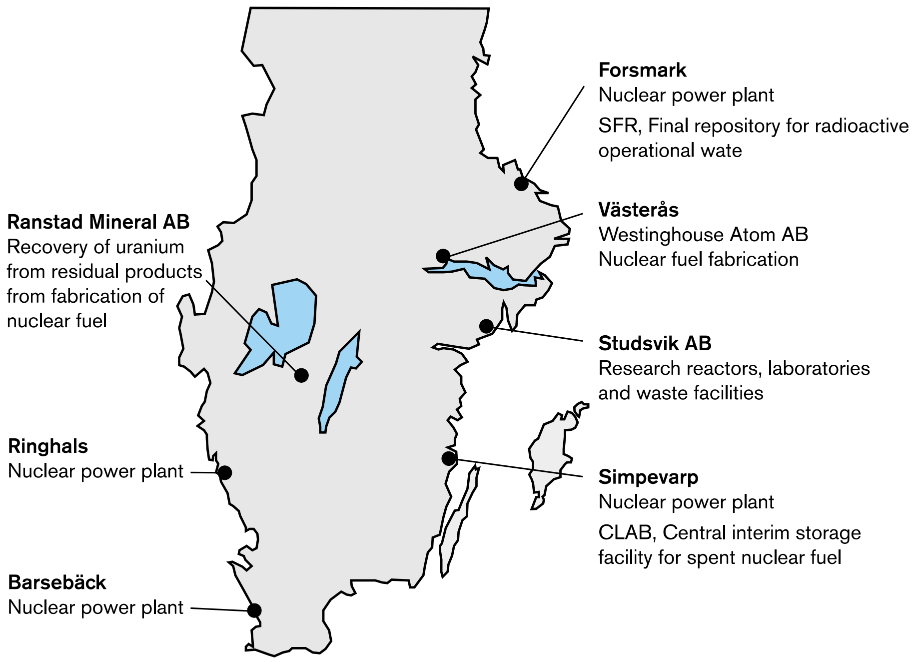


Figure 1-1. *Nuclear installations in Sweden.*

1.2 Waste types and volumes

IAEA

International Atomic Energy Agency

Radioactivity level

Measured in becquerels (Bq)

1 Bq = 1 disintegration per second

Different types of nuclear waste require different management and disposal. It is therefore necessary to classify the waste in suitable categories. This is done in slightly different ways in different countries. In Sweden we apply a system that coincides closely with that developed by the IAEA /1–1/, see Table 1-1. Firstly, the waste is divided into short- and long-lived waste, based on the half-life of the radionuclides it contains. Secondly, based on the radioactivity level, a distinction is made between low-level waste (LLW), intermediate-level waste (ILW) and high-level waste (HLW). Each waste type can be described in these terms. One speaks, for example, of long-lived low- and intermediate-level waste (LILW).

In principle, each waste category requires special management and disposal procedures. In practice, however, the waste categories can be consolidated into main groups that are deposited in the same final repository. In Sweden, the waste is divided into three such main groups, each of which has its own final repository, see Figure 1-2.

Table 1-1. Classification of radioactive waste (simplified and non-quantitative)

Half-life		**Radioactivity level**		
Short-lived	**Long-lived**	**Low-level**	**Intermediate-level**	**High-level**
Low content of radionuclides with half-life longer than about 30 years.	Significant content of nuclides with half-life longer than about 30 years.	Requires neither cooling nor radiation shielding.	Requires radiation shielding, but not cooling.	Requires cooling and radiation shielding.

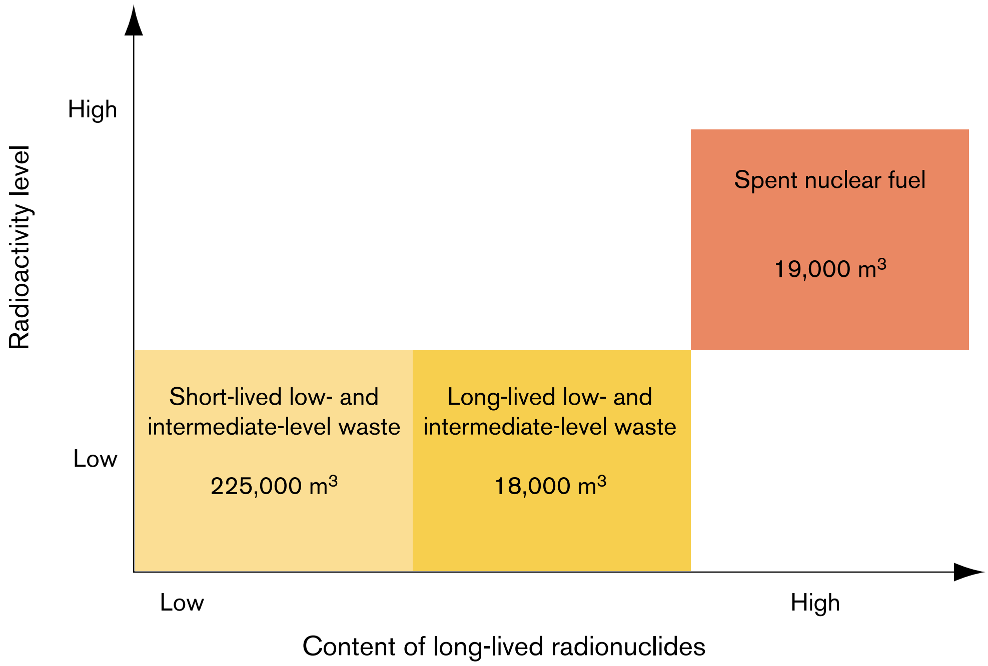


Figure 1-2. *Schematic grouping of waste categories with respect to requirements on final disposal. The volumes pertain to waste from 40 years of reactor operation.*

Short-lived LILW

Most of the waste from the NPPs, about 85% of the volume, is short-lived and low- and intermediate-level. It is formed both during reactor operation and when the plants are decommissioned. Operational waste consists of e.g. spent filters, replaced components and used protective clothing, while decommissioning waste consists of e.g. metal scrap and building materials.

LILW
Low- and intermediate-level waste

Spent nuclear fuel

Spent nuclear fuel comprises a small fraction of the total waste volume, but contains by far most of all radioactivity, both short- and long-lived. This high-level waste is hazardous to man and the environment for a very long time.

Long-lived LILW

Spent components from the reactor core or its immediate vicinity are an example of long-lived LILW. It contains long-lived radionuclides that are formed when stable substances in e.g. steel are converted to radionuclides by the intensive neutron radiation from the reactor core. This waste also constitutes a potential hazard in a long-term perspective.

Neutron radiation
Stream of neutrons, electrically neutral nuclear particles

1.3 Spent nuclear fuel

The fuel in the Swedish nuclear power reactors consists of uranium dioxide. The uranium consists of different isotopes. Uranium-235, with a concentration of 3–4 percent, is fissionable. In the fabrication of nuclear fuel, a powder of uranium dioxide is pressed into ceramic cylinders called pellets. The pellets are stacked in cladding tubes approximately four metres long to form fuel rods, which are in turn assembled into bundles called fuel assemblies, see Figure 1-3.

Isotope
Atoms of the same element with different atomic weights, some may be radioactive

Figure 1-3. *Fuel assembly in fuel factory in Västerås.*

Before the fuel is loaded into the reactor, it can be handled without radiation shielding. When it is taken out after 4–5 years, it is unchanged in form but nuclear fission of uranium-235 has now given rise to some 60 or so fission products, many of which are radioactive. Most of these are short-lived, but some are long-lived.

Actinides

Group of 15 heavy elements which only have radioactive isotopes

Moreover, during reactor operation, uranium-238 nuclei in the fuel have captured neutrons and formed heavier nuclides, such as plutonium and americium. These elements, along with uranium, belong to the group known as actinides, several of which have long half-lives.

The decay (disintegration) of the radionuclides in spent fuel causes them to emit radiation and generate heat, so-called decay heat. Eventually, as the short-lived substances decay, the radioactivity in the spent fuel will be dominated by the long-lived substances, mainly actinides.

When the fissionable uranium in the nuclear fuel has been consumed to a given level, nuclear fission in the reactor can no longer proceed. When the fuel is discharged from the reactor, it therefore contains a residue of approximately 0.6 percent uranium-235. Furthermore, fissionable plutonium has formed in the fuel during reactor operation. The content of this fissionable material is the basis for the alternative of reprocessing the spent nuclear fuel and thereby separating uranium and plutonium for reuse in new nuclear fuel, see section 4.3.

The described properties of spent nuclear fuel are important points of departure for spent fuel management. Radiation shielding is required in connection with all handling, storage and disposal. The decay heat requires cooling to prevent the nuclear fuel from overheating. The content of long-lived radionuclides is decisive in determining the layout of a final repository. The presence of fissionable material requires measures to prevent criticality (see section 1.4.1) from occurring or the fuel from getting into the wrong hands.

1.4 How dangerous is spent nuclear fuel?

The risks associated with spent nuclear fuel can be described in terms of radiotoxicity and accessibility. Radiotoxicity describes the harm which the radiation from the radioactive substances can cause if people are exposed to it. Accessibility describes the degree to which a person can be exposed to radiation in different situations, for example during transport, interim storage ore final disposal. The goal of spent fuel management is to minimize the risks by rendering the fuel inaccessible to man and the environment.

1.4.1 Radiotoxicity

External and internal radiation

Some radioactive substances emit radiation, including gamma rays, that penetrates into or through matter. Such substances are therefore dangerous to man even when the radiation source is located outside the body (external radiation). Spent fuel emits powerful radiation after discharge from the reactor. The radiation in the vicinity of the fuel quickly gives lethal doses to unprotected persons. The radiation decays rapidly, but still requires protective measures for a very long time.

Other radioactive substances emit alpha and beta particles, which have such a short range that the substances are only dangerous if they enter the body, via food or inhalation, and emit their radiation there (internal radiation). In spent nuclear fuel, radioactive isotopes of elements such as cesium, strontium, americium and plutonium are dangerous from this viewpoint.

Time scale

The short-lived substances (nuclides) with high radioactivity decay within the course of a few hundred years /1-2/. After the most short-lived nuclides have decayed, cesium-137 and strontium-90 dominate the radiotoxicity of the fuel. After a thousand years, radiotoxicity is dominated by a few nuclides, the actinides and their decay products. After around 100,000 years, the radiotoxicity of the spent fuel has declined to the same level as the natural uranium minerals from which it was fabricated. The radiotoxicity of such minerals, as well as eventually that of the spent fuel, is dominated by radiation from decay products of the uranium (radium, radon, polonium, etc.).

Criticality

Nuclear fuel has another property that constitutes a potential hazard. If the fuel assemblies are placed together with suitable materials and at a suitable distance from each other, a self-sustaining chain reaction can result. This phenomenon is called criticality. Spent nuclear fuel is discharged from the reactor for the very reason that its ability to sustain chain reactions has fallen to a low level, but in extreme situations the residual content of fissionable materials may nevertheless

Alpha radiation
consists of particles (atomic nuclei of helium) and is rapidly stopped when it hits a solid object. An alpha-emitting substance is only harmful if it enters the body via ingestion or inhalation.

Beta radiation
consists of electrons. It has a longer range than alpha radiation and can cause damage to unprotected skin. However, the greatest risk is associated with ingestion or inhalation.

Gamma radiation
consists of electromagnetic radiation of very short wavelength. The radiation has a long range and can easily penetrate living tissue. Stopping gamma rays requires radiation shields of lead, concrete or water.

Chain reaction
Neutrons from a split atom collide with another atom, splitting it and causing it to emit neutrons which in turn split other atoms, etc.

give rise to criticality. Regardless of how the spent fuel is handled, however, the chain reaction can never be so violent that it leads to a nuclear explosion. The danger of criticality can be avoided by designing transport casks and facilities in such a way, and building them with such materials, that criticality is not possible.

Heat output

One tonne of fuel develops about 30,000 kilowatts of thermal power during reactor operation. After discharge from the reactor it must be cooled. At the time of the planned deep disposal, the decay heat will have declined to about one kilowatt. In the deep repository, heat output is primarily of importance in determining how densely the canisters can be emplaced without the temperature locally in the repository becoming too high.

1.4.2 Accessibility

A common way to deal with hazardous substances is to render them inaccessible. This is what is done, for example, when hazardous chemicals are kept in special containers and/or sealed spaces, or when medicines are kept in locked medical cabinets.

The principle is the same for handling of spent fuel. Protection against its hazard (radiotoxicity) is achieved by rendering the fuel inaccessible, usually by isolating the fuel behind some kind of barrier. The fuel itself is a ceramic material that has low solubility in water, which contributes to rendering the radionuclides inaccessible. The most long-lived nuclides have particularly low accessibility in most situations, for example in a deep repository for spent nuclear fuel.

Whenever the spent nuclear fuel is handled, its accessibility is limited: during transport by means of special containers (transport casks), and during storage periods by keeping the fuel in water pools. The transport casks and the water in the storage pools cool the fuel and shield off the radiation it emits.

SKB's plan is to render the waste inaccessible to man and the environment by disposing of it at a depth of approximately 500 metres in the crystalline basement.

2 Facilities and programme

SKB has been operating a final repository for short-lived waste, an interim storage facility for spent nuclear fuel and a system for transporting spent nuclear fuel and other waste for many years now. Several new facilities are needed to manage and dispose of all nuclear waste in Sweden.

Efforts are now primarily focused on siting and building an encapsulation plant and a deep repository for spent nuclear fuel. The plan is that the first canister with spent fuel is to be deposited in the repository in around 2015. Decisions on siting, construction and operation will be taken in steps based on an increasingly detailed body of data. An important goal is to prepare applications for siting permits for the two facilities. The applications are to be based on a thorough EIA process in consultation with municipalities, regulatory authorities, nearby residents and others who can be assumed to be affected.

2.1 Existing and planned facilities

The waste from the nuclear power plants is managed today in SKB's facilities CLAB and SFR. In order to be able to dispose of all waste, SKB needs to expand these facilities and augment the system with new facilities. Efforts are now focused on siting and building a system for final disposal of spent nuclear fuel. The system is based on encapsulation of the fuel in copper canisters and emplacement of the canisters (deposition) at a depth of approximately 500 metres in the bedrock in accordance with the KBS-3 method (see Chapter 6).

EIA/EIS
Environmental Impact Assessment/ Statement

CLAB
Central interim storage facility for spent nuclear fuel

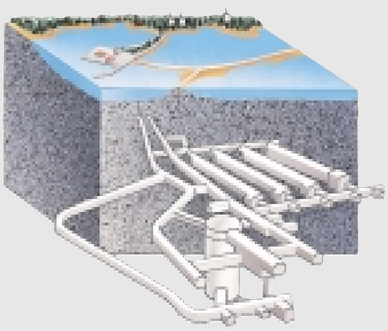
SFR
Final repository for radioactive operational waste

KBS
Nuclear Fuel Safety

SFR

Start of construction: 1983

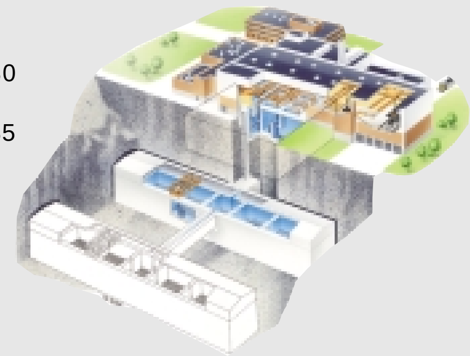
Start of operation: 1988



CLAB

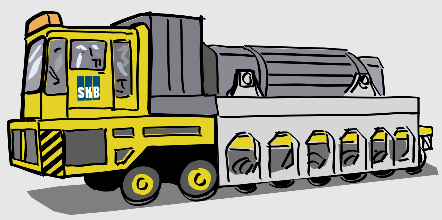
Start of construction: 1980

Start of operation: 1985



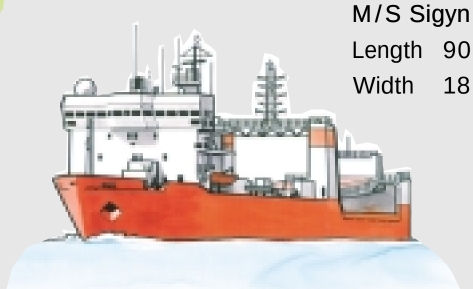
Terminal vehicle

Weight	about 32 tonnes
Length	about 12 m
Width	about 3 m
Load capacity	125 tonnes



M/S Sigyn

Length	90 m
Width	18 m



Facilities for interim storage and final disposal of the three main categories of waste, as well as planned siting of the remaining final repository, are shown in Table 2-1.

Table 2-1. Nuclear installations for interim storage and final disposal
Need for expansions and new facilities in bold style.

Waste type	Interim storage	Final disposal
Short-lived LILW		
Operational waste	No need	SFR Expansion
Decommissioning waste	No need	SFR Expansion
Spent nuclear fuel	CLAB	Encapsulation plant Deep repository
Long-lived LILW	CLAB, Studsvik (or possibly new facility)	Final repository

Deep repository
SKB's name for the final repository for spent nuclear fuel in accordance with the KBS-3 method

2.1.1 Short-lived LILW

Short-lived operational waste from the Swedish NPPs is transported today to the final repository for radioactive operational waste, SFR, at the Forsmark NPP. SFR has been in operation since 1988. An expansion of the capacity of SFR for operational waste is currently planned.

The plan for final disposal of short-lived decommissioning waste from nuclear installations is another expansion of SFR, for which a new application and a Government decision will be required.

2.1.2 Spent nuclear fuel

CLAB at the NPP in Oskarshamn was taken into service in 1985. The spent nuclear fuel is stored in a rock cavern for about 30 years in water pools with a total capacity of approximately 5,000 tonnes of uranium. At the beginning of 2000, CLAB contained spent fuel equivalent to approximately 3,200 tonnes of uranium.

Construction is under way on a new rock cavern, equal in size to the first. It will be finished in 2004, when the present-day pools are expected to be filled with fuel.

Two nuclear installations are needed for final disposal: an encapsulation plant and a deep repository. In addition, SKB intends to build a factory for the fabrication of copper canisters. The canister factory is not a nuclear installation. The new facilities in the system are described in Chapter 6.

2.1.3 Long-lived LILW

Core components and reactor internals come from inside the reactor core or its immediate vicinity

Long-lived low- and intermediate waste (LILW) consisting of e.g. core components and reactor internals is stored today in the pools at CLAB. In order not to occupy capacity in CLAB intended for fuel storage, it is being considered whether to arrange interim storage of LILW in some other way. An alternative would be a rock vault in SFR. Another alternative is an existing rock cavern at Simpevarp.

SKB is planning to build a special final repository for long-lived LILW. The siting of this repository will not take place for another 30 years or so. One possible site is in connection with the deep repository for spent fuel. In this case, the waste would be deposited in a separate deposition area. The repository can take the form of rock vaults similar to those for short-lived ILW in SFR.

Other possible sitings are at SFR or at a separate site. A preliminary safety assessment has been carried out /2-1/.

2.1.4 Transportation system

In Sweden, shipments of spent nuclear fuel and other radioactive waste go by sea, since all NPPs and waste facilities are situated along the coast. The transportation system consists of the ship M/S Sigyn, a number of transport containers/casks and special vehicles for loading and unloading. The system has been gradually built out and augmented since the start of operation in 1982.

2.1.5 Siting

The situation for siting of the remaining facilities can be summarized as follows:

- Work is under way to find a site for the deep repository.
- SKB's main alternative for the encapsulation plant is at CLAB. Alternatively, the facility can be located on the same site as the deep repository or possibly in connection with an existing nuclear installation.
- The planned expansion of SFR for decommissioning waste does not entail any new siting.
- A possible interim storage facility for core components could be sited in a rock vault in SFR or an existing rock cavern at Simpevarp.
- A final repository for long-lived LILW is needed, but it will be another 30 years before the question of siting and construction arises. When the question comes up, it appears likely that the alternatives that will be considered then are siting adjacent to an existing deep repository, at SFR or on another site.

This means that the deep repository is the component of central interest for the siting work at this time. The others are associated with existing nuclear installations or the deep repository, or else their siting is far in the future. The current siting process is therefore focused on an application for a deep repository for spent nuclear fuel.

2.2 Programme for encapsulation and deep disposal

Demonstration deposition of 200 to 400 canisters is followed by an evaluation

For several years now, SKB has been pursuing a programme aimed at building an encapsulation plant and a deep repository in order to implement the deep disposal of spent nuclear fuel in an initial stage. This entails depositing 5–10% of the fuel, equivalent to approximately 200–400 canisters. Before a decision is made to continue with further deposition, an evaluation will be made of experience from the first stage and other newly-acquired knowledge.

According to the strategy established in conjunction with RD&D-Programme 92 /2-2/, decisions on siting, construction and operation are to be made successively based on an increasingly detailed body of data. An interim goal is to gather the supporting material needed to apply for a siting permit for the two facilities. Plans for the next few years are presented in the description of the site investigation phase in Chapter 13.

Figure 2-1. *Canister Laboratory in Oskarshamn.*

Producer responsibility entails that the owners of the nuclear power plants are responsible for managing and disposing of the waste in a safe manner. They have jointly formed SKB to discharge this responsibility.

SKB has established its own laboratories for the purpose of developing and testing the encapsulation and deep disposal technology, see Figures 2-1 and 2-2. The Canister Laboratory in Oskarshamn, which was put into operation in 1998, serves as the centre for development of encapsulation technology and training of personnel for the encapsulation plant. The Äspö Hard Rock Laboratory (HRL) has been SKB's main resource for developing, testing and demonstrating the deep disposal technology since 1995.

The work is being conducted with high intensity. This is important in order to make use of available competencies and resources and to concretely discharge the producer responsibility borne by the nuclear power industry according to the Nuclear Activities Act. However, adequate time must also be allowed for a thorough EIA process and a democratic consensus-building process in the concerned municipalities.

Figure 2-2. *Äspö HRL near the Simpevarp Peninsula, north of Oskarshamn.*

Figure 2-3 shows SKB's reference timetable for the encapsulation plant and the deep repository. The dates are preliminary, in view of e.g. the uncertainties associated with the extensive decision-making process.

The initial operation of encapsulation and deposition entails an initial stage (demonstration) of the deep repository. SKB estimates that initial operation can be commenced in around 2015. This entails postponement by about two years compared with the timetable presented in RD&D-Programme 98 /2-3/.

Before a decision is made regarding continued operation, initial operation will be evaluated. The evaluation is planned to take place in parallel with initial operation. If the evaluation provides support for continued regular operation, the latter can be commenced without prolonged delay. In this way, construction and human resources can be used in a rational manner.

The length of the operating phase is directly dependent on the operating life of the NPPs. In SKB's reference alternative it is 40 years, with the exception of Barsebäck 1, which was shut down on the last of November 1999. The operating life of the deep repository will then extend a bit into the 2050s, and the whole programme may be concluded in around 2060.

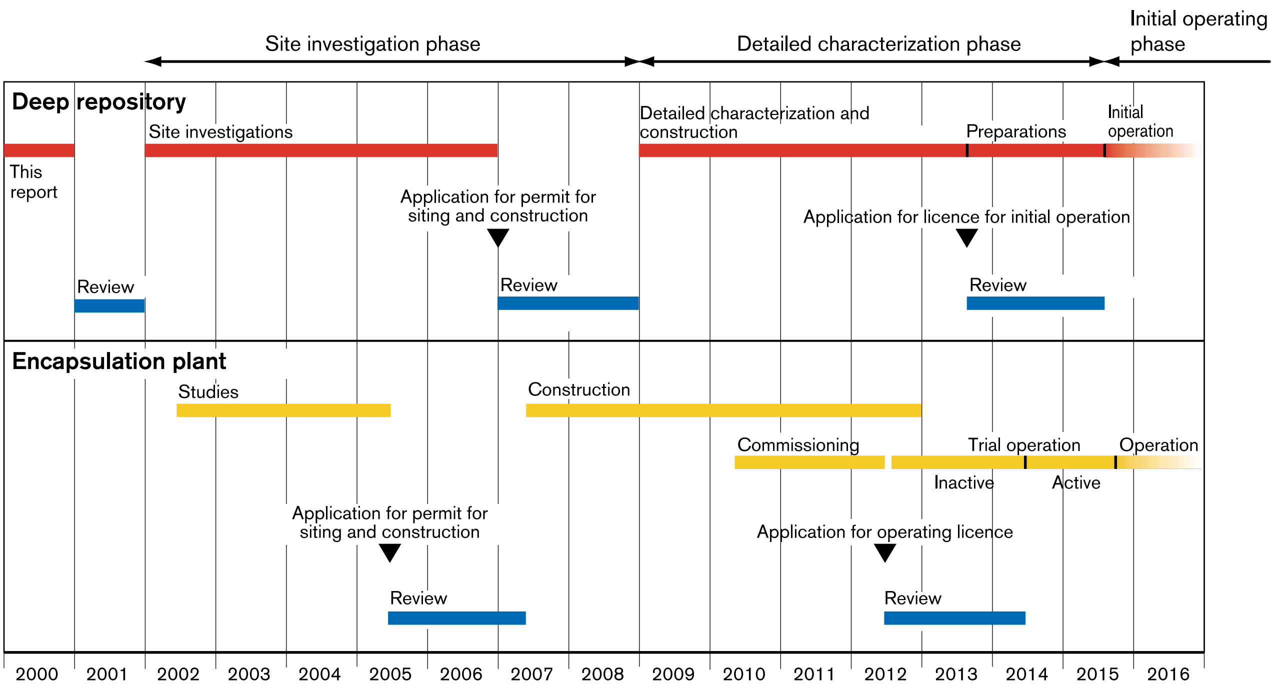


***Figure 2-3.** Reference timetable for deep repository and encapsulation plant.*

3 Regulatory framework for nuclear fuel management

Management and final disposal of nuclear waste is regulated by Swedish law, which prescribes clear producer responsibility and lays down the rules for financing and licensing of e.g. a deep repository. The regulations issued by the regulatory authorities contain detailed requirements on radiation protection and safety.

One of the requirements in the Nuclear Activities Act is that SKB shall prepare a programme for its research and development work every third year. In conjunction with the review of the programme, the Government can stipulate conditions for the continued work and request a supplementary account.

The Government stipulated such conditions after review and evaluation of RD&D-Programme 98. SKB has responded to these conditions by preparing a new account of alternative strategies and systems, an evaluation of the background material for selection of sites for site investigations, and a programme for the site investigations.

This chapter contains an overview of the laws and regulations that govern the management of spent nuclear fuel. The conditions stipulated by the Government in conjunction with the review of SKB's RD&D-Programme 98 are also summarized.

The Swedish regulatory framework for the management of the nuclear waste differs in essential respects from both other Swedish legal provisions concerning handling of environmentally hazardous substances and equivalent legislation in other countries. This is probably attributable to the fact that management of spent nuclear fuel in Sweden became a major public issue at a relatively early stage.

The foundation for the regulatory framework for nuclear waste management was laid in the early 1980s. The risks of the spent fuel were held up as an important problem in the Swedish debate concerning nuclear power. The basic division of responsibility for nuclear waste between the state and industry was established during the same period. The regulatory framework has been developed and refined from the mid-1980s. Several important changes have been made in recent years as well, but the main elements of the model have endured. The development of the waste programme and the regulatory framework viewed from a societal and energy policy perspective is described in a special report /3-1/.

Acts and ordinances

SFS 1984:3	Act on Nuclear Activities
SFS 1984:14	Ordinance on Nuclear Activities
SFS 1992:1537	Act on the Financing of Future Expenses for Spent Nuclear Fuel etc.
SFS 1988:220	Radiation Protection Act
SFS 1998:808	Environmental Code
SFS 1998:899	Ordinance on environmentally hazardous activities and public health
SFS 1998:896	Ordinance on management of land and water areas etc.
SFS 1987:10	Planning and Building Act

3.1 Laws and regulations

Provisions governing the management of nuclear waste are mainly found in the Nuclear Activities Act, the Nuclear Activities Ordinance, the Environmental Code, the Act on the Financing of Future Expenses for Spent Nuclear Fuel, the Radiation Protection Act, the Planning and Building Act, as well as in certain permits and guidelines issued by the Government.

3.1.1 Responsibility

SKI

Statens Kärnkraft-inspektion (Swedish Nuclear Power Inspectorate)

SSI

Statens Strålskydds-institut (National Radiation Protection Institute)

KASAM

Statens råd för kärnavfallsfrågor (Swedish National Council for Nuclear Waste)

The companies that hold licences to operate nuclear power plants are responsible for taking all the measures needed in order to manage and dispose of the nuclear waste in a safe manner. This also includes decommissioning and dismantling the NPPs at the end of their service lives and conducting research and development on waste disposal. A programme for the research and development activities must be submitted to the authorities every third year. The licensees are liable for all the costs for waste management.

Licences to operate NPPs are held by Forsmarks Kraftgrupp AB (the Forsmark NPP), OKG Aktiebolag (the Oskarshamn NPP), Ringhals AB (the Ringhals NPP) and Barsebäck Kraft AB (the Barsebäck NPP). Svensk Kärnbränslehantering AB (the Swedish Nuclear Fuel and Waste Management Company), SKB, which is jointly owned by the power utilities, has been charged with responsibility for nuclear waste management from the time the waste leaves the nuclear power plants.

SKI is responsible for reviewing the RD&D programmes and submitting statements of comment to the Government. SSI is an important reviewing body in this review process. KASAM submits its own statement of comment. SKI and SSI are further responsible for supervision of SKB's activities in accordance with the Nuclear Activities Act and the Radiation Protection Act.

Excerpt from the Nuclear Activities Act

§ 10

The holder of a licence for nuclear activities shall be responsible for ensuring that all measures are taken that are required for

1. maintaining safety, with reference to the nature of the activities and the conditions in which they are conducted;
2. ensuring the safe management and final disposal of nuclear waste arising in the activities or nuclear material arising therein that is not re-used, and
3. safely decommissioning and dismantling plants in which activities are no longer to be conducted.

§ 11

The holder of a licence to own or operate a nuclear power reactor shall, over and above the provisions in Section 10, ensure that such comprehensive research and development work is conducted as is required for the fulfilment of the provisions of Section 10, subsections 2 and 3.

§ 12

The holder of a licence to own or operate a nuclear power reactor shall, in consultation with other reactor owners, prepare or have prepared a programme for the comprehensive research and development work and other measures specified in Section 10, subsections 2 and 3, and in Section 11. The programme shall contain both an overview of all measures that may be required and a detailed description of those measures that are intended to be taken within a period of at least six years. The programme shall be submitted to the Government or the authority designated by the Government every third year for examination and evaluation. In conjunction with this examination and evaluation, whatever conditions are needed with regard to the continued research and development work may be stipulated.
Act (1992:1536).

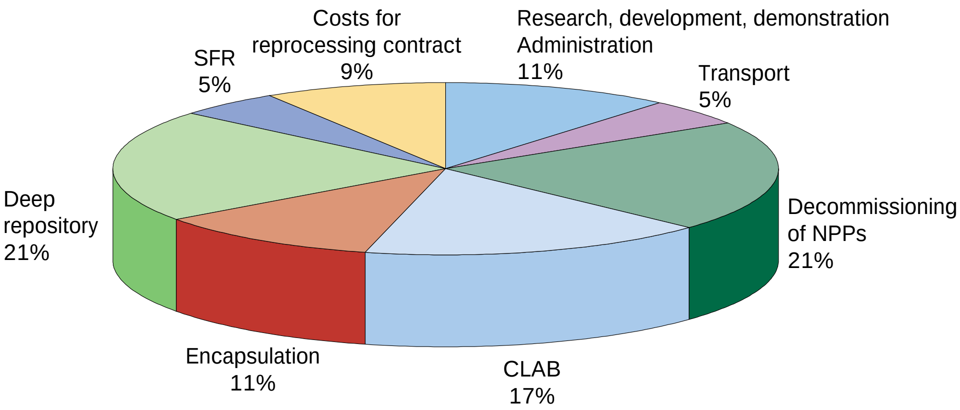


Figure 3-1. *Breakdown of the costs in SKB's programme for management and disposal of Sweden's radioactive waste.*

3.1.2 Financing

According to the Financing Act, the costs of the nuclear waste programme shall be covered by the nuclear power utilities. Monies are collected in a special reserve fund, the Nuclear Waste Fund at the National Debt Office. Every year, SKB carries out calculations of the total future cost. SKI checks the calculations and the Government then makes a decision on the charges to be paid by the nuclear power utilities for the coming year. The charge paid to the Nuclear Waste Fund during 2000 is approximately one öre (100 öre = 1 Swedish krona; USD 1 = SEK 9.50) per kilowatt-hour of nuclear-generated electricity.

Approximately SEK 13 billion has been used through 1999 for SKB's work with construction and operation of facilities and for research and development. At the beginning of 2000, the Nuclear Waste Fund contained approximately SEK 23 billion. Including interest income in the years to come, this covers approximately 90% of the estimated future costs, around SEK 47 billion at current prices. The breakdown of these costs is illustrated by Figure 3-1.

The Financing Act also requires that the power utilities pledge securities in order to guarantee that the necessary contributions will be made to the Nuclear Waste Fund, even if the NPPs are decommissioned before the reserve fund is fully paid up or if additional costs arise in the future due to unforeseen events /3-2/.

3.1.3 Rules for licensing

Important provisions for licensing of facilities for management and disposal of nuclear power waste are provided in the Nuclear Activities Act and the Environmental Code.

Government permits and licences under the Nuclear Activities Act are required in order to build, own and operate a nuclear installation (such as a deep repository). Permits to handle and transport nuclear materials or nuclear waste are issued by SKI and SSI. The Nuclear Activities Act imposes stringent demands on safety, which is an important point of departure for the nuclear waste programme.

Licensing under the Environmental Code is subject to consideration of such issues as the siting, nature and size of the facility as well as land use, environment and transport. The Ordinance on environmental activities and public health (SFS 1998:899) makes it clear that permits/licences under the Environmental Code are required for facilities for final disposal of spent nuclear fuel, nuclear waste or other radioactive waste. In connection with licensing under the

Environmental Code, consideration is given to various land use interests in order to avoid a conflict between different interests wherever possible. According to the Ordinance on management of land and water areas (SFS 1998:896), SKI shall, in consultation with the National Board of Housing, Building and Planning and other concerned central authorities as well as concerned county administrative boards, submit information on those areas deemed to be of national interest for final disposal of spent nuclear fuel and nuclear waste.

The Government makes decisions on permits/licences under the Nuclear Activities Act, while the Environmental Court examines permit/licence applications under the Environmental Code. Before the Environmental Court pronounces judgement, the Government shall assess the permissibility of the facility in accordance with Chapter 17 of the Environmental Code.

EIS

Environmental Impact Statement (the document resulting from an EIA = Environmental Impact Assessment)

Both the Nuclear Activities Act and the Environmental Code prescribe that the applicant must prepare an environmental impact statement (EIS) as a basis for the examination of permit applications under the two acts. During the EIA procedure leading up to preparation of the EIS, it is the applicant's obligation to consult with public authorities, municipalities, the public and whatever organizations can be assumed to be particularly affected. Consultation shall include the siting, scope, design and environmental impact of the planned activity, as well as the form and content of the EIS.

A permit under the Radiation Protection Act is required in order to transport, store and possess a radioactive substance. However, a permit under this act is not required for activities that have permits under the Nuclear Activities Act, since radiation protection aspects are taken into account in conjunction with licensing under the Nuclear Activities Act.

The Planning and Building Act requires a building permit for arranging stockpiles or storage yards, as well as for arranging tunnels or rock caverns. In a detailed development plan, the municipality must declare that a building permit is not required for certain measures, for example construction of tunnels and rock caverns.

In summary, the creation of a deep repository for spent nuclear fuel must be preceded by licensing under the Nuclear Activities Act, the Environmental Code and the Planning and Building Act.

A Government decision to site an activity in a given municipality is normally predicated on the concerned municipality's having approved the proposed siting. In other words, the municipality has a veto. For certain types of facilities, for example deep repositories for spent nuclear fuel, however, the Government may grant a permit under the Environmental Code despite the fact that the municipal council has not approved the proposed siting. The requirement for this is that "the activity is of the utmost importance with regard to the national interest", with the added condition that "this shall not apply where another site is considered more appropriate for the activity or if an appropriate site has been designated for the activity in another municipality which is likely to approve the site." A siting that does not have the support of the municipal council in the concerned municipality conflicts with SKB's express view that a deep repository should only be sited where the safety requirements are met and the municipality is positive towards the siting.

SKB believes that the siting of a deep repository must have the support of the concerned municipality

3.1.4 Regulations concerning safety and radiation protection

The requirements on safety and radiation protection for waste facilities are concretized in regulations from SKI and SSI, which are largely based on internationally established principles for radiation protection.

An important document that deals with radioactive waste management is the IAEA's waste convention /3-3/. This international agreement, to which Sweden has acceded, stipulates what aspects are to be considered in order to achieve safe waste management. Besides safety and radiation protection, waste issues and questions of an ethical nature are dealt with. Examples are that the waste shall be disposed of in the state in which it was generated if this can be done in a safe manner, that the public shall be kept informed, and that undue burdens shall not be imposed on future generations. Other international agreements with a bearing on waste management concluded under the auspices of the IAEA deal with e.g. transport of radioactive material and non-proliferation of nuclear material /3-4, 3-5/. The London Convention and addenda to it prohibit dumping of radioactive waste in the sea as well as disposal in sea sediments. Safe management of radioactive waste is also dealt within Agenda 21 and in the EU in the "Treaty Establishing the European Atomic Energy Community". Swedish legislation takes the international agreements into account, and SKI's regulations concretize the requirements in the laws.

SSI's regulations are based on internationally established principles for radiation protection. Radiation protection shall be as strong as is economically and technically feasible. Individuals shall be guaranteed protection by the use of limit values for doses. Not just man, but also flora and fauna shall be protected. The protection shall be equivalent for present and future generations and for individuals inside and outside the national boundaries. Radiation protection in management and in disposal shall be equivalent to that in other radiological activities, for example reactor operation and radiological work at hospitals.

Long-term radiation protection and safety after closure of a deep repository impose new demands on legislation, among other things due to the long time spans involved. SSI has issued specific regulations on the protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste (SSI FS 1998:1). Among other things, the regulations stipulate that a repository for spent nuclear fuel shall be designed so that the annual risk of harmful effects after closure does not exceed one in a million for a representative individual in the group exposed to the greatest risk.

In July 2000, SKI distributed a proposal for regulations and general recommendations on safety in conjunction with the final disposal of nuclear waste. The proposed regulations /3-6/, which are currently being circulated for review and comment, apply to a final repository in rock and include fundamental safety provisions, requirements on design and construction, and directions for the safety assessment and the safety report. One of the fundamental requirements is that post-closure safety shall be maintained by means of a passive barrier system.

3.2 Government conditions and SKB's accounts

According to the requirements of the Nuclear Activities Act, SKB shall prepare a programme for the comprehensive research and development work that is needed for management and final disposal of waste from nuclear installations, and for decommissioning and dismantling of these installations and disposal of the waste then arising. The programme shall be submitted every third year for review and evaluation to the Government or the authority designated by the Government. In conjunction therewith, the Government may stipulate conditions for the continued research and development work.

SKB submitted the first complete research programme, R&D-Programme 86, in 1986. The content of the programme has subsequently been progressively revised based on the results of SKB's studies, safety assessments and R&D and RD&D programmes, review and commentary procedures, decisions by the regulatory authorities, and the conditions for the content of the programme determined by the Government on this basis. An overview of the development of the nuclear waste programme over a period of approximately 25 years is presented in RD&D-Programme 98 /3-7/.

R&D
Research and Development

RD&D
Research, Development and Demonstration

In January 2000, the Government made a decision regarding SKB's RD&D-Programme 98, based on review by the authorities and a broad commentary procedure, and stipulated the following conditions for the continued research and development activities. SKB shall:

> "Supplement the analysis of alternative system designs. Firstly, the implications of the *zero alternative* (a description of what happens if the planned measure does not come about) shall be elucidated. Furthermore, the alternative *Very Deep Holes* (final disposal in boreholes at a depth of several kilometres) shall be elucidated with a focus on the scope and content of the research and development programme needed in order for this method to be compared with the KBS-3 method on equivalent grounds.
>
> "Present an integrated evaluation of completed feasibility studies and other background material for selection of sites for site investigations.
>
> Present a clear programme for site investigations."

The Government further decided that SKB shall consult with concerned municipalities, county administrative boards and regulatory authorities in the preparation of the requested accounts and give an account of these consultations.

In February 2000, SKB described in a letter to SKI its plan for preparing the account requested by the Government and gathering the material called for by concerned authorities and municipalities in preparation for their decisions regarding site investigations. The goal was set to be able to submit an integrated account of method, site selection and programme for the site investigation phase (this report) in December of 2000.

The present account will be circulated for review and comment during the spring of 2001

According to the Government decision, SKI shall scrutinize SKB's account in a similar manner to an ordinary RD&D programme, which entails e.g. extensive circulation for review and comment. SKI described the main elements in its review in a letter to SKB in February 2000. It is planned to include circulation to the same reviewing bodies as for RD&D-Programme 98 plus new feasibility study municipalities, hearings together with SSI in municipalities which SKB proposes for site investigations, its own review and a statement of comment to the Government. SKI judged that a statement of comment could subsequently be submitted to the Government in June of 2001.

SKB has responded to the conditions in the Government's decision by:

- Summarizing in Part II of this report a new survey of alternative strategies and systems for management of spent nuclear fuel. The survey also includes an updated summary of the system analysis for KBS-3 /3-8/ as well as of the safety assessment SR 97 /3-9/.
- Systematically and in detail describing and evaluating in a report alternative strategies and system solutions vis-à-vis requirements in Swedish law and international conventions /3-10/.
- Elucidating in a report the implications of the zero alternative and its consequences /3-11/.
- Describing in a report the RD&D programme that would need to be carried out in order to compare the alternative Very Deep Holes with the KBS-3 method on equivalent grounds /3-12/.
- Presenting in Part III of this report an integrated evaluation of completed feasibility studies and other background material for selection of sites for site investigations.
- Presenting in Part IV of this report SKB's proposed programme for site investigations.
- Presenting in an appendix to this report an account of the consultation that has been carried out in connection with the preparation of the requested accounts.

Part II - Method

4 Strategies

The question of how the spent nuclear fuel is to be managed and disposed of is dealt with in this and the following three chapters. What are the requirements? What are the alternatives? What are the consequences? What happens if we don't do anything?

In Sweden there is a firmly underpinned main line: disposal in the Swedish bedrock based on the KBS-3 method. Recurrent presentation and review of the RD&D programmes and several Government decisions have confirmed the chosen direction. The main purpose of the survey of possible strategies is therefore to present the reasoning that has led to this main line.

In the so-called zero alternative, storage in CLAB continues indefinitely. The consequences of a depletion of competence in the nuclear waste field can be troublesome even in the short term. In the long term, safety cannot be ensured. The chapter concludes with an overview of nuclear waste management in other countries.

In conjunction with RD&D-Programme 98, SKB presented a survey of the alternatives for management and disposal of spent nuclear fuel /4-1/ and a system account of the main alternative – geological disposal according to the KBS-3 method /4-2/. After review and circulation of RD&D-Programme 98 for comment, SKI and SSI have offered viewpoints /4-3/ on these reports, as well as on the content and structure of a system analysis. In its decision on RD&D-Programme 98, the Government stipulated conditions regarding certain supplementary analysis of alternative system designs (see section 3.2). These viewpoints and conditions were included in the premises for the latest system analysis /4-4/.

In a system analysis, different alternatives for solving a problem are examined and compared with defined requirements. The purpose is to find the best solution to the problem. The following concepts are used in the system analysis:

Strategy A general technical approach to solving the problem at hand (e.g. geological disposal).

System A set of interacting facilities etcetera required for the practical application of a strategy (e.g. interim storage facility, transport vehicles, harbour, canister factory, encapsulation plant, deep repository).

System variant Alternative designs of the facilities etcetera that belong to a system.

The system analysis has been carried out in steps. Based on a compilation of all relevant requirements on spent fuel management, possible strategies are first described and compared (this chapter). Which system best satisfies the requirements is then determined for the chosen strategy (Chapter 5). Finally, an analysis is performed of the chosen system with its various system variants (Chapter 6). The word ”method” is used in the sense of mode of proceeding. KBS-3, for example, is a method for building a deep repository, while Very Deep Holes is another method. The method underlies the system design.

4.1 Requirements on system for management of spent nuclear fuel

As a point of departure for the system analysis, the requirements in Swedish law and in the international agreements which Sweden has undertaken to abide by are first summarized. The most important agreements in this context are the IAEA's waste convention /4-5/ and the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter /4-6/.

Fundamental requirements

Radioactive waste should, as far as is compatible with the safety of the management of such material, be disposed of in the State in which it was generated. (IAEA's waste convention /4-5/).

In the management of spent nuclear fuel, appropriate steps shall be taken to avoid imposing undue burdens on future generations (IAEA's waste convention).

Disposal of spent nuclear fuel may not take place in the ocean or on the seabed outside the country's internal waters (London Convention with protocol /4-6, 4-7/).

The owners of the nuclear power plants are responsible for ensuring that nuclear waste, or nuclear material that is not reused, is managed and disposed of in a safe manner (Act on Nuclear Activities, SFS 1984:3).

No one may take preparatory measures for the purpose of erecting a nuclear power reactor in Sweden (Act on Nuclear Activities, SFS 1984:3).

Environment (Environmental Code, SFS 1998:808)

Sustainable development shall be promoted assuring a healthy and sound environment for present and future generations.

Land, water and the physical environment shall otherwise be used in such a manner as to secure sustainable management from an ecological, social, cultural and economic viewpoint.

Reuse and recycling, as well as other management of materials, shall be striven for with a view to achieving sustainable natural cycles.

Safety (Act on Nuclear Activities SFS 1984:3, SKI's regulations /4-8/)

Safety shall rest on multiple barriers.

Events which can affect the system's barriers shall be identified.

The system shall possess acceptable tolerance to defects in the barriers and events which can affect them.

In a final repository for spent nuclear fuel, the barriers shall, after closure of the repository, provide the requisite safety without monitoring and maintenance.

A system for management of spent nuclear fuel shall be tolerant to malfunctions of component parts and possess high reliability.

Tried-and-tested design principles and solutions shall preferably be used.

Radiation protection (Radiation Protection Act SFS 1988:220, SSI's regulations /4-9/)

The impact of ionizing radiation on man and the environment shall be calculated and found to be acceptable both now and in the future.

Optimization shall take place and the best possible technology shall be taken into account. Optimization pertains to minimization of radiation doses as much as possible. The best possible technology is the most effective measure for limiting releases and harmful effects of radioactive substances that does not entail unreasonable costs.

A final repository for spent nuclear fuel shall be designed so that the annual risk to a representative individual in the group exposed to the greatest risk does not exceed one in a million.

Non-proliferation of nuclear material and nuclear waste - safeguards

Illicit traffic in nuclear material or nuclear waste shall be prevented (IAEA /4-10/).

4.2 Overview of possible strategies and systems

The point of departure for the analysis is that the spent nuclear fuel is in CLAB (see section 2.1). If SKB's future plans are disregarded, what alternatives exist for continued management of the spent fuel? What will the consequences be, and how well do the different alternatives satisfy the requirements in laws and international agreements?

There are two possible main ways of dealing with the spent nuclear fuel, see Figure 4-1. One entails regarding the fuel as a resource, the other as waste. In order to make this choice, it is necessary to examine and evaluate several possible strategies. A systematic evaluation of the strategies vis-à-vis the stipulated requirements in turn requires general descriptions of the systems needed to implement them. For several of the strategies – reprocessing and transmutation, supervised storage and geological disposal – there are several alternative systems.

If one chooses to regard spent nuclear fuel as a resource, then it must be reprocessed. The purpose is to extract more energy from the spent fuel and at the same time convert (transmute) long-lived radionuclides to stable or less long-lived nuclides. This strategy is called "reprocessing and transmutation" below. Even after implementation of this strategy, there will be radioactive waste that must be dealt with in a similar manner to spent nuclear fuel. Reprocessing and transmutation thus entails that one of the waste strategies in Figure 4-1 must also be chosen at a later stage.

Reprocessing and transmutation of the spent nuclear fuel is a step not only in waste management, but also in nuclear fuel supply. Furthermore, the more advanced concepts for reprocessing and transmutation require development of new types of reactors. Both today's reprocessing and transmutation technology and the new concepts are therefore associated with future energy systems. Here we limit ourselves to analyzing the consequences for waste management.

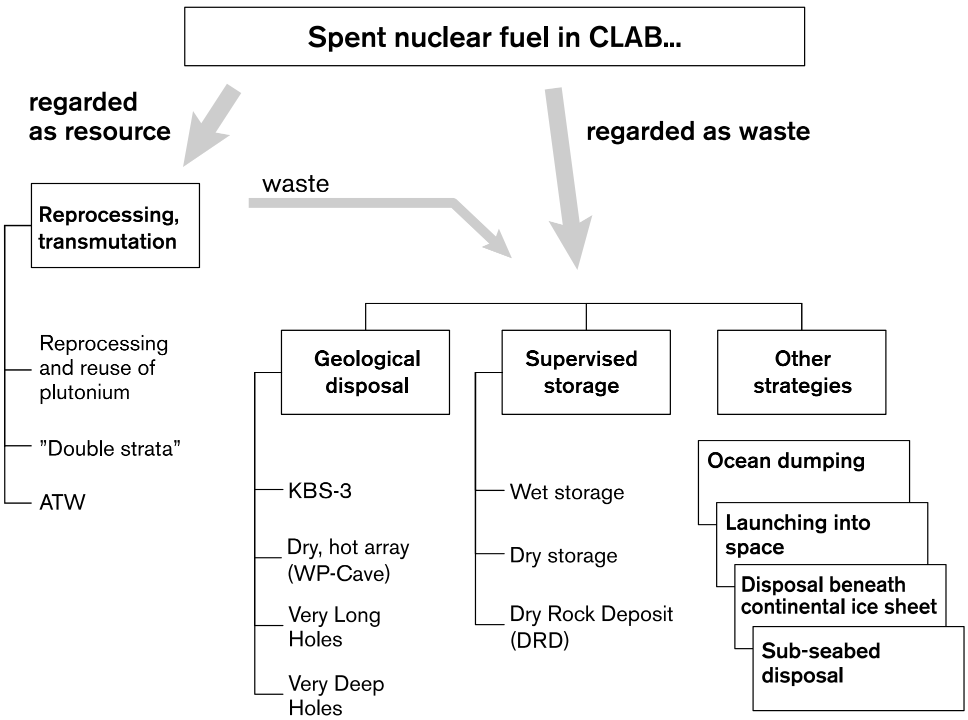


Figure 4-1. *The studied strategies and alternative systems. After reprocessing and transmutation, high-level waste remains which must in turn be managed.*

If the spent fuel is regarded as waste, there are several possible strategies. Of these, ocean dumping, sub-seabed disposal and disposal beneath continental ice sheets are not possible alternatives for Sweden, since they violate international agreements which Sweden has undertaken to abide by. None of the alternatives is in line with the ambitions of the IAEA's waste convention, which says that waste should be disposed of in the State in which it was generated. Furthermore, ocean dumping and sub-seabed disposal violate the London Convention /4-6/ and its protocol /4-7/.

Launching the spent fuel into space would require enormous quantities of rocket fuel and be very costly. In practice, reprocessing is needed to reduce the waste volumes. American studies concerning reprocessing waste show that a safe system can be designed based on existing space technology /4-11/. Not even in the event of serious accidents, such as for example that the space vehicle should explode, is any dispersal of radioactive substances to the atmosphere expected according to the studies. However, after an accident, containers of radioactive waste could land anywhere, and should be retrieved. Due to the need for reprocessing and the great resources that are needed for launching into space, the strategy is not judged to be the most efficient measure for limiting releases and harmful effects of the radioactive substances (radiation protection requirement in section 4.1).

Ocean dumping, sub-seabed disposal, disposal beneath continental ice sheets and launching into space can be ruled out and are not dealt with further in this report. For system descriptions and more thorough evaluation, reference is made to the background report /4-4/.

Supervised storage of spent nuclear fuel is included as a step in most strategies, and experience exists of supervised storage from all nuclear power countries. It is used for interim storage for up to several decades pending further treatment. In SKI's evaluation of SKB's research and development programme /4-12/, supervised storage has been proposed as a strategy for isolating spent nuclear fuel for a very long time, several thousand years.

Geological disposal is the predominant strategy internationally for disposal of spent nuclear fuel or long-lived HLW from reprocessing. All major research and development programmes in the area are aimed at developing technology for geological disposal.

Against this background, the description below focuses on the alternatives reprocessing and transmutation, supervised storage and geological disposal.

4.3 Reprocessing and transmutation

Spent nuclear fuel contains fissionable substances, mainly plutonium, that can be used as raw material in the fabrication of new nuclear fuel. Reprocessing is an advanced nuclear process for recovering these substances from spent nuclear fuel. The process entails dissolving the nuclear fuel in acid, whereupon the substances can be separated from the solution. The residue consists of e.g. fission products and activation products, and comprises a high-level, long-lived waste.

Transmutation of an element entails converting it to another element by means of a nuclear reaction – for example nuclear fission or radioactive decay. Nuclear fission in today's light-water reactors (LWRs) is a form of transmutation. In general, however, transmutation refers to conversion of long-lived nuclides, other than uranium and plutonium, to stable or less long-lived nuclides. Actinides are transmuted by nuclear fission with neutrons. The large quantities of energy that are then liberated can be utilized for electricity production.

Fission products
Nuclides, often radioactive, formed when atoms are split

Activation products
Radionuclides formed when elements capture neutrons

Light-water reactor (LWR)
Ordinary water is used in the Swedish reactors

Actinides
Group of 15 heavy elements which only have radioactive isotopes

The purpose of reprocessing and transmutation is to make efficient use of the uranium raw material and to convert long-lived radionuclides in the spent nuclear fuel to short-lived or stable nuclides. There are several possible systems for reprocessing and transmutation, with different stresses on these purposes. We describe three alternatives here:

- Reprocessing and recycling of uranium and plutonium.
- Transmutation as a complement to recycling of uranium and plutonium.
- Transmutation without purification of plutonium.

The first alternative is already being applied today. The other two systems are objects of research.

4.3.1 Reprocessing and recycling of uranium and plutonium

The process is illustrated schematically in Figure 4-2. The main purpose is to utilize the uranium raw material efficiently. In reprocessing, uranium and plutonium are separated from other actinides and from the fission products in the spent fuel. The extracted uranium and plutonium are used to make MOX fuel, which is used in LWRs, for example of the type in operation in Sweden today, or in fast reactors. The remainder, consisting of other actinides, fission products and certain activation products, form a high-level, long-lived liquid waste that is vitrified (turned into glass) to make it stable and easy to handle.

MOX fuel
Mixed Oxide Fuel
Nuclear fuel fabricated from a mixture of uranium and plutonium oxide

Light-water reactor (LWR)
Ordinary water is used as a coolant and a moderator (to give neutrons a suitable velocity for nuclear fission). Only uranium-235, plutonium-239 and plutonium-241 can undergo fission.

Fast reactor
The neutrons have a high velocity. In principle, all actinides can undergo fission.

By reprocessing and recovering uranium and plutonium, the need for mined uranium can be substantially reduced, especially if fast reactors are available. After a small number of recyclings in LWRs, however, the spent MOX fuel has a plutonium content that is not suitable for fabrication of new fuel. It then becomes radioactive waste. The result is that the original spent nuclear fuel has been transformed into high-level vitrified waste, spent MOX fuel and some other radioactive waste from reprocessing and fuel fabrication.

Viewed in relation to the energy that is produced, recovery of uranium and plutonium reduces the total quantity of actinides to be disposed of, along with the total quantity of plutonium that has to be managed as waste. In principle, however, the same system is required to deal with the spent MOX fuel and the high-level vitrified waste as in the case of direct disposal of spent nuclear fuel.

There are plants for reprocessing and recovery of uranium and plutonium in France and the UK. Spent nuclear fuel from some other countries lacking their own plants is also reprocessed there. Figure 4-3 shows the French reprocessing plant in La Hague.

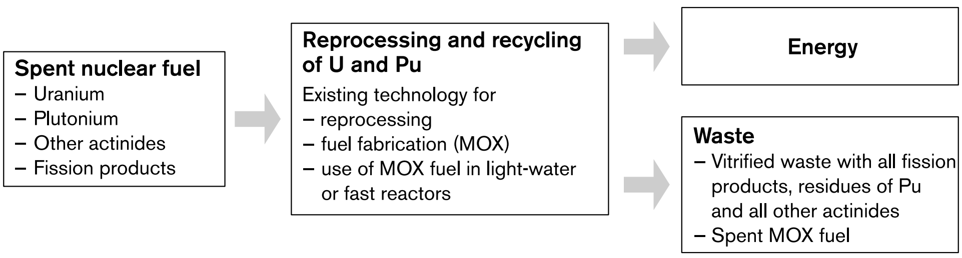


Figure 4-2. *Reprocessing and recycling of uranium and plutonium.*

Figure 4-3. *Reprocessing plant in La Hague, France.*

4.3.2 Transmutation as a complement to recycling of uranium and plutonium

In order to achieve an efficient transmutation of the majority of the long-lived radionuclides in spent nuclear fuel (uranium or MOX fuel), it is first necessary to separate them from the spent fuel (partitioning), and then fabricate new fuel (transmutation fuel) and operate a reactor with this fuel to carry out the transmutation.

There are several technical problems that must be solved. One problem is being able to partition all the long-lived substances that are to be transmuted. A new reprocessing technology needs to be developed for this purpose.

Accelerator-driven reactor
A reactor that needs to be supplied with neutrons from an external neutron source. The neutron source consists of an accelerator which shoots protons at a target of, for example, lead. A large number of neutrons are liberated for every proton that hits the target.

Accelerator
Plant in which electrically charged particles are given a high velocity.

Another problem is that new plutonium and other long-lived actinides are formed in fuel containing uranium, such as MOX fuel. Therefore, in order to transmute the actinides without simultaneously forming new ones, fuel that does not contain uranium must be used in the transmutation process. New reactor technology based on fast reactors and/or accelerator-driven reactors therefore needs to be developed. Repeated cycles of reprocessing, fuel fabrication and reactor irradiation are required for complete transmutation. The process is summarized in Figure 4-4.

In addition to present-day plants for recycling of uranium and plutonium as MOX fuel, plants for another fuel cycle with other reprocessing processes and reactors are therefore needed. The system is therefore called "double strata". Plants for the second cycle only exist today in the research stage or on the drawing table. Extensive research and development is needed to design a system that can be used on an industrial scale. The system is mainly being studied in France and Japan.

In transmutation, the long-lived transuranic elements undergo fission and form fission products. To put it simply, the long-lived radiotoxicity represented by the actinides in the spent nuclear fuel is exchanged for a greater but more short-lived radiotoxicity. Waste volumes, as well as the content of radioactive substances, are determined by the partitioning processes, transmutation and the number of recyclings. The quantity of long-lived radionuclides in the waste is reduced, but some high-level, long-lived waste will always remain and require similar management as spent nuclear fuel.

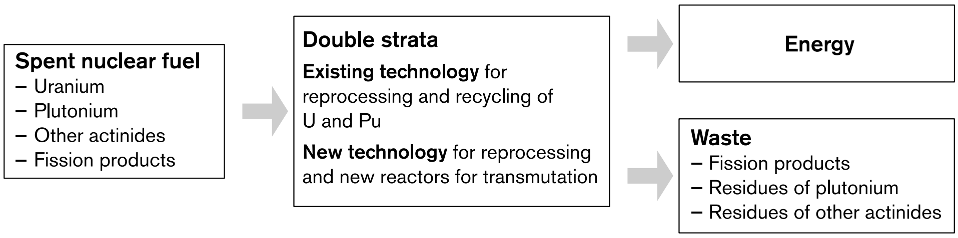


Figure 4-4. *Transmutation as a complement to recycling of uranium and plutonium – double strata.*

4.3.3 Transmutation without purification of plutonium

The possibilities of directly separating all transuranics and certain other long-lived isotopes in spent nuclear fuel from uranium and transmuting them have recently been studied in the USA /4-13/. The idea is to use accelerator-driven transmutation, ATW. The purpose is to reduce the quantity of long-lived substances to be disposed of, reduce the long-lived radiotoxicity of the waste, and at the same time make use of the energy remaining in the spent fuel. Extensive research and development is required for the system to become a reality.

ATW
Accelerator Transmutation of Waste.
Transmutation in an accelerator-driven reactor

In principle, the same waste types are obtained as in the alternative "transmutation as a complement to recycling of uranium and plutonium". Since partitioning processes, transmutation and the number of recyclings is not the same, however, the waste volumes and the content of radionuclides differ. The content of long-lived radionuclides decreases radically, but some of the waste has to be dealt with in a similar manner to spent nuclear fuel.

4.3.4 Evaluation of reprocessing and transmutation

Reprocessing for recycling of uranium and plutonium has been dismissed as a possibility in Sweden for economic and political reasons /4-14/. More advanced reprocessing and transmutation, where the spent fuel's content of long-lived radioactive substances is radically reduced, requires considerable research and development and several technically complicated plants. These include power-producing nuclear reactors, which the Nuclear Activities Act says may not be erected in Sweden.

It is as yet uncertain how efficient transmutation can become and how many cycles the material should undergo. Ascertaining this is included in the research programme that must be carried out in order for reprocessing and transmutation to be a realizable strategy. The development of a functioning system is expected to be costly and take a long time. An assessment based on the American study is that it will take approximately 100 years to develop the system and transmute the fuel. It is not reasonable to expect that Sweden could develop and build such a system on its own. In any case, some high-level, long-lived waste will remain that must be dealt with in a similar manner to spent nuclear fuel.

Even after reprocessing/transmutation, some waste remains

Since reprocessing, fuel fabrication and transmutation entail extensive handling of high-level radionuclides, it can be expected that operation and maintenance of the plants will give higher radiation doses to the personnel than the other described strategies.

The result of the transmutation will be to exchange the relatively low long-term radiotoxicity of the actinides for a relatively greater radiotoxicity with a shorter time span. If waste management is regarded in isolation, it is doubtful whether this is in line with the law's requirement of optimization and utilization of the best possible technology to minimize the radiation doses. The benefit of the produced energy should also be weighed into a complete evaluation.

Safeguards
International system for control and verification of nuclear material to prevent unauthorized diversion

Plutonium can be used for weapons production. Reprocessing that entails purification of plutonium therefore imposes particularly stringent demands on safeguards.

4.4 Supervised storage

Supervised storage for a long period of time, several thousand years, has been proposed in the review and commentary of SKB's research and development programme as a strategy for managing the spent nuclear fuel.

Experience of and research on supervised storage for such a long period as thousands of years is lacking today. On the other hand, practical experience of supervised storage for a more limited period of time is available from several countries, since interim storage is always included as a step in the management of spent nuclear fuel. There are systems in operation for wet storage and for dry storage.

4.4.1 Wet storage

In wet storage, the spent nuclear fuel is stored in water-filled pools. The water cools and radiation-shields the fuel. To prevent corrosion of the fuel assemblies, the requirements on water quality are stringent. The pool water is circulated in a closed system with heat exchangers and cleanup filters. Some of the water evaporates due to the heat emitted by the fuel and must be replaced. Continuous supervision of heat exchange, water cleanup and water supply, as well as monitoring and maintenance of the plant, are required to ensure adequate safety.

Experience from wet storage is available from a number of countries, including CLAB in Sweden, see Figure 4-5. As long as operation and maintenance are handled properly, a wet store is deemed to be able to be operated for at least a hundred years, probably longer, with as good safety as today.

4.4.2 Dry storage

There are two variants for dry storage, both of which are used at several places in the world, see Figure 4-6. In one, the spent fuel is placed in specially designed cylindrical, thick-walled containers of metal or concrete, which are stored outdoors or in special storage buildings. Metal containers can also be used as transport casks. The heat is dissipated through the container to the surrounding air. The containers constitute radiation shields and prevent the dispersal of radioactive substances.

In the second variant of dry storage, the spent fuel is placed in thin-walled but fairly gastight metal containers. These are then placed in a building with fixed

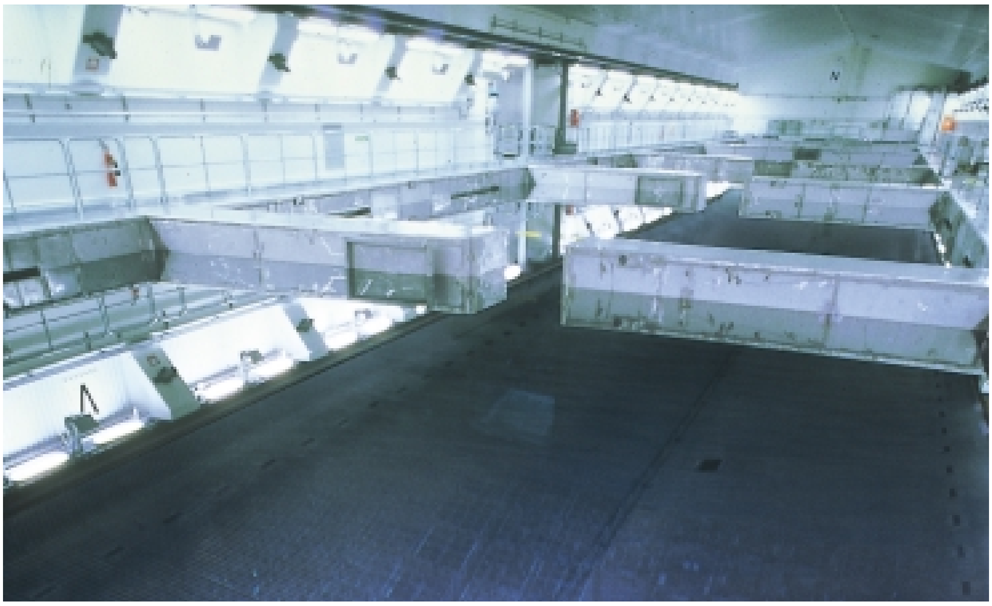


Figure 4-5. *Wet storage in CLAB.*

Figure 4-6. *Dry interim storage of spent nuclear fuel in Gorleben, Germany.*

ventilated storage positions of concrete that enable heat to be dissipated. The thin-walled metal container acts as a barrier to the dispersal of radioactive substances. Radiation shielding and protection against mechanical damage is provided by the surrounding concrete structure and the building.

Due to the low thermal conductivity of air, the temperature of the fuel is considerably higher in dry storage than in wet. To prevent corrosion, the air in the containers is often replaced with a suitable gas. Continuous operation consists solely of ventilation and is simpler than in wet storage. As in wet storage, the plant must be monitored and the containers must be checked at regular intervals.

Safety assessments, e.g. from Germany /4-15/, show that dry storage can take place in a safe manner. It can probably go on for several hundred years without safety being jeopardized. In a longer time perspective than that, the uncertainties become greater, as in wet storage. One problem with dry storage is the high temperatures and the chemical and mechanical degradation processes to which they can lead.

4.4.3 The DRD concept

A proposed variant of dry storage, DRD (Dry Rock Deposit), is intended for storage for a very long time, several thousand years. The principal difference between DRD and dry storage systems in place today is the space surrounding the storage containers. In the DRD concept, containers with fuel are placed in a self-draining rock cavern built in a rock formation that projects up above a surrounding depression /4-16, 17, 18/. After deposition the rock cavern is closed. No drainage pumping or cooling is required. The idea is to minimize the need for maintenance and monitoring so that storage can take place for a long time.

DRD
Dry Rock Deposit

The uncertainties that are associated with the dry storage systems in operation today also apply to DRD. High temperatures and the presence of oxygen make it difficult to demonstrate that the containers will remain intact for thousands of years.

4.4.4 Evaluation of supervised storage

Long-term wet and dry storage require some form of periodic inspection and maintenance. Studies of CLAB show that in a time perspective of several hundred years, rock reinforcements and rock structures need to be checked and repaired /4-19/. Containers for dry storage also probably need to be replaced or reconditioned.

Supervised storage imposes burdens on future generations and provides inadequate protection if supervision should cease

Environmental, safety and radiation protection requirements can be complied with as long as human supervision and control are maintained. If it should cease for some reason, the physical barriers are not adequate to satisfy the requirements. As the name implies, supervised storage requires supervision. This means that the requirement of not imposing undue burdens on future generations is not met.

At the facilities for supervised storage that are in operation today, there are systems for safeguards consisting of a combination of access barriers, accounting systems, monitoring, and unannounced inspections. In the event of the loss of accounting systems and/or monitoring, the protection of stored nuclear materials is weak.

4.5 Geological disposal

A passive barrier requires no maintenance

Geological disposal is based on the utilization of a geological environment that is stable over a very long time. The basic principle for geological disposal is that the waste is surrounded by several passive barriers that support and complement each other. The safety of the repository would be adequate even if one barrier were defective or failed to function as intended.

Safety is based on a combination of the natural barrier comprised by the rock, the great depth and the environment at repository depth, plus man-made engineered barriers. The engineered barriers are adapted to conditions at repository depth and designed so that they isolate the spent fuel in this environment and prevent dispersal of radioactive substances for long periods of time. The spent fuel itself has extremely low solubility in water, and most radionuclides that are radiotoxic in the long term have limited mobility in geological environments. The engineered barriers are designed so that they do not require any maintenance after deposition is concluded and the repository is closed.

Crystalline rock types such as granite and gneiss comprise most of Sweden's bedrock

Internationally, geological disposal is the predominant strategy for final disposal of spent nuclear fuel or long-lived HLW from reprocessing, see section 4.8. Different geological settings have been studied according to the natural conditions existing in different countries. The bedrock being considered in Sweden is crystalline rock that is between one and two billion years old. Clay and salt formations are among the geological media being investigated in other countries.

If human intrusion is disregarded, man and the environment can only be exposed to the radioactivity from the deep repository if radionuclides are released from the repository and transported up to the surface with the groundwater. An environment in the rock is therefore sought where the engineered barriers can be expected to remain intact in a long time perspective and where water exchange with the surface is small. A general conclusion from investigations in deep boreholes in Sweden and abroad is that water exchange with the ground surface declines with depth, while salinity, temperature and rock stresses increase, see Figure 4-7. These conditions affect the design of a repository and its engineered barriers as well as long-term safety.

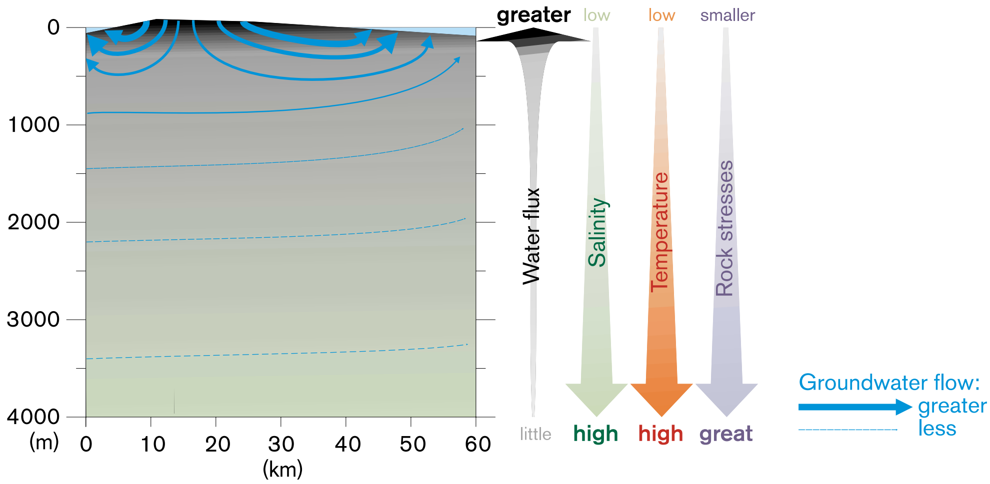


Figure 4-7. *Some conditions in the bedrock that influence the prospects for building a deep repository.*

Another important factor is the occurrence of dissolved oxygen in the groundwater, since oxygen influences corrosion of the canister and the repository's ability to retard the transport of radionuclides. Sampling of groundwater in boreholes shows that groundwater at great depth is free of dissolved oxygen and that the oxygen that is dissolved in precipitation water is consumed near the ground surface.

A final repository for spent fuel in Swedish crystalline bedrock can be designed in several ways (see Chapter 5). For comparison with other strategies we use the main alternative here, a repository based on the KBS-3 method.

In a KBS-3-type repository, the fuel is encapsulated in leaktight canisters of corrosion-resistant copper with a pressure-bearing insert of cast iron. The canisters are deposited at a depth of about 500 metres in vertical holes bored from the tunnels. The canisters are embedded in a buffer of bentonite clay that protects them against minor rock movements and prevents or retards the transport of radionuclides to the rock if any canisters should leak. The repository depth of about 500 metres is deemed to be sufficient to offer an environment where the engineered barriers can retain their function even in the face of extensive changes on the ground surface. Experience from the construction of tunnels and rock caverns is also available from this depth.

Safety in the operation of a KBS-3-type deep repository has been described in /4-20/. The long-term post-closure safety of a KBS-3 repository has been assessed by SKB in several safety reports /4-21, 22, 23/. Finland is also planning a deep repository based on KBS-3, and has assessed post-closure safety on several occasions /4-24, 25/. The safety assessments show that the safety risks in connection with geological disposal according to the KBS-3 method are very small, both now and in the far distant future.

4.5.1 Evaluation of geological disposal

Geological disposal can satisfy the overall requirements

Geological disposal satisfies the overall requirements. A deep repository can be built in Sweden. The waste can be managed and disposed of without imposing burdens on future generations.

The requirement on multiple barriers can be met. When all fuel has been deposited and the repository has been closed, long-term safety is not dependent upon inspection or maintenance. In Sweden, as well as in other countries, many years of experience exist from construction in rock, mainly in the mining industry. The materials in the engineered barriers have been selected with a view towards being able to demonstrate their durability and function in the geological environment over very long time spans.

Analyses of systems based on the KBS-3 method show that a geological repository can be designed so that the calculated radiation doses are well below those stipulated by the regulatory authorities as being acceptable during construction and operation, as well as after closure. The costs of developing technology and carrying out waste disposal can be calculated and are covered by funds set aside in a special reserve fund, the Nuclear Waste Fund. Thus, it is a strategy that satisfies the requirement on good radiation protection at reasonable costs.

Retrieval is possible but requires considerable resources

Geological disposal offers good prospects for preventing unauthorized persons from gaining access to the spent fuel. The spent nuclear fuel will be supervised during the operating phase. Even after closure, some form of safeguards will probably be established. Retrieving the spent nuclear fuel from a closed geological repository will not be impossible, but it will involve an effort comparable to that of a large industrial or construction project. Given sufficient resources, future generations will be able to access the spent nuclear fuel if they wish, see also section 6.6.

4.6 Overall assessment

In the system analysis /4-4/, a systematic evaluation of the alternatives has been carried out against the requirements given in section 4.1. The judgements of the different strategies are summarized in Table 4-1. SKB concludes that geological disposal is the strategy that best satisfies the stipulated requirements.

Table 4-1. SKB's judgements of the studied strategies

Strategy	SKB's judgement
Ocean dumping, sub-seabed disposal, disposal beneath continental ice sheet	Violates international agreements.
Supervised storage	Responsibility is shifted to future generations. Does not satisfy the safety and radiation protection requirements in the long term.
Launching into space	Resource-intensive, costly. Probably presupposes reprocessing.
Reprocessing/transmutation	Requires a complicated nuclear system, including new reactors. Extensive research is needed. Waste must be dealt with in a similar manner to nuclear fuel. Associated with future energy systems. Not economically and politically feasible in Sweden.
Geological disposal	Can satisfy all requirements. Can be implemented today. Future generations have the option of retrieving the waste.

4.7 The zero alternative

The concept of zero alternative is used in conjunction with environmental impact assessments. In the Environmental Code (SFS 1998:808), it is defined as: "a description of the consequences if the activity or measure is not implemented." According to the National Board of Housing, Building and Planning /4-26/, the zero alternative is "a frame of reference with which to compare the project proposal by predicting what would happen if the project were not implemented."

For the management of spent nuclear fuel, the zero alternative entails that the present-day storage of the fuel in CLAB continues indefinitely, see Figure 4-8. The consequences have been examined in a separate report /4-27/. Sometimes the zero alternative is equated with the alternative of supervised storage. But there is a fundamental difference. Supervised storage is a proposed solution to the waste problem, with several possible technical solutions, see section 4.4, while the zero alternative entails doing nothing compared with today's situation, aside from continued operation and maintenance of CLAB.

CLAB consists of a receiving section at ground level and a storage section located in a rock cavern whose roof is 25–30 metres below the ground surface. All handling and storage of fuel takes place in water pools. The water, which both cools the fuel and shields off the radiation, circulates in a closed system through heat exchangers and cleanup filters.

The facility, which was put into service in 1985, is built to be operated for about 60 years. To maintain safety, personnel must be present at all times to supervise and maintain the systems. Approximately 100 persons are needed to operate CLAB.

4.7.1 Prolonged storage in CLAB

In order to shed light on the consequences of the zero alternative, the possibilities of storing the fuel in CLAB for 100–200 years have been investigated /4-27/. One fundamental premise in the study is that operation and maintenance of the facility are of the same quality as today. Another premise is that the infrastructure around CLAB – i.e. power and water supply, waste disposal etc. – remains intact.

Figure 4-8. *The zero alternative entails that fuel is stored indefinitely in CLAB (the above-ground facility is seen in the foreground) at the Oskarshamn Nuclear Power Plant.*

The building structures in the storage section are estimated to have a lifetime of about 200 years. A follow-up programme indicating the need for repair and renovation of certain parts would be required, however. Rock reinforcements cannot be projected to last 200 years based on present-day knowledge. Here a follow-up programme and replacement of certain parts will be necessary. Installations and handling equipment generally have a limited service life, but can be replaced and modernized. The same applies to electrical and control equipment. Modernization and replacement of components is performed continuously in CLAB even today.

Provided that the quality of the water meets relevant specifications, it is judged that the fuel can be stored in water for a long time without suffering damage. However, experience and research are lacking to assess the consequences of storage beyond 100–200 years.

The study also contains an analysis of possible accidents during prolonged storage at CLAB. The analysis shows that the consequences for the surrounding environment of accidents during prolonged storage decreases with time. At the same time, the time margins for rectifying operational disturbances increases, since the activity of the fuel, and thereby its heat output, declines with time. As a result, even severe accidents, which could result from ageing, will have limited consequences for the surrounding environment.

All factors considered, we can assume that CLAB can – with certain renovation and modernization measures, and as long as our present-day society lasts – be operated safely for 100 years or more.

4.7.2 Abandonment of CLAB

Radiation dose is given in milliSieverts (mSv). The natural background dose in Sweden is approximately 1 mSv/y

What happens if the facility has to be abandoned due to e.g. war or environmental disasters? Even if, for example, important pumps should stop, it will take around a month before the water in the pools has evaporated to the point where the fuel is exposed. But if more water has not been added by then, the temperature can become so high that the fuel is damaged. In the worst cases, the radiation doses may then be relatively high (on the order of 10–100 mSv/y /4-28/).

The fuel in CLAB can only be exposed if more water evaporates due to heating by the fuel than flows into the facility from the surrounding rock. After storage for approximately 250 years, the decay heat in the fuel will have decreased so much that the water does not evaporate any more. The point in time when CLAB is abandoned is thus crucial for the consequences. Another factor of importance is whether the facility has to be abandoned immediately, or whether some advance warning is obtained so that measures can be taken to mitigate the consequences for the surrounding environment.

Contamination
Radioactive pollution

One serious consequence of abandonment of CLAB is if the facility were to be contaminated to such an extent that resumption of control and management of the fuel at a later date would be difficult. Retrieving the fuel from an abandoned CLAB would, in other words, be a difficult and risky venture.

4.7.3 Consequences of the zero alternative

In the short term, the zero alternative entails continuing to operate CLAB in the same way as today while replacing ageing parts of the facility as needed. Environmental, safety and radiation protection requirements will be complied with as long as supervision and control are maintained. However, we can neither expect nor ask that future generations should set aside resources for supervision and maintenance far into the future. If supervision and control should for some reason cease, the consequences could be serious.

One risk if interim storage in CLAB is prolonged and no additional measures are taken to manage the spent fuel is that we will lose the competence that has been built up to manage and dispose of spent nuclear fuel in a safe manner. This includes both the technical-scientific expertise possessed by regulatory authorities and SKB, and general knowledge possessed by national and local politicians and the general public. In its statement of comment on SKB's RD&D-Programme 98 /4-29/, KASAM says:

KASAM
Statens råd för kärnavfallsfrågor (Swedish National Council for Nuclear Waste)

> "Even prolonging interim storage until new knowledge and technology can lead to better methods may have a serious consequence. The development of a fruitful idea into a mature, proven technology takes decades when the technology has to live up to the demands made on management and disposal of high-level waste. In the meantime, the competence in the nuclear waste field currently possessed by regulatory authorities, nuclear power utilities, SKB, universities and consultants will dissipate. If nuclear power has moreover been phased out at the same time and the waste management work has been put on hold, the field will lose its interest and fail to attract new recruits. Enthusiasm, broad expertise and detailed knowledge exist now. To risk wasting these resources is not a good alternative."

4.8 International overview

In its report /4-30/, SKI says that SKB should compile an international overview of management of spent nuclear fuel and high-level waste from reprocessing: "A deep and broad history of method selection and its review should be published in a special report that explains the course of events in a pedagogical manner for wide circles in society. International developments should also be presented in a similar manner in a separate report." The latter of these is found in /4-31/, whose content is summarized in this section. The deep and broad history is provided in /4-14/.

The countries included in the overview are the USA, Japan, Russia, Canada, France, Finland, Switzerland, Spain, the UK and Germany, see Table 4-2.

All of the aforementioned countries plan for geological disposal of spent nuclear fuel or high-level waste from reprocessing. The choice of method and geological formations differs, however. Underground research laboratories have been built at a number of places in different types of bedrock. Some places have been singled out as candidates for geological repositories: Olkiluoto in Finland, Yucca Mountain in the USA and Gorleben in Germany. The last-named site has now been called into question for political reasons.

Reprocessing plants exist in France, the UK and Russia, and Japan plans to start one in 2005. Power utilities in Japan, Switzerland, Belgium, the Netherlands and Germany are sending some of their fuel to be reprocessed in France or the UK. The USA, Canada, Finland and Spain are planning for direct disposal of the spent nuclear fuel.

Tablel 4-2. Nuclear power reactors and installed capacity (October, 2000)

	Number of reactors	Installed capacity (thousand megawatts)
USA	103	96
France	59	63
Japan	52	43
Germany	19	21
Russia	29	20
UK	35	13
Canada	14	10
Sweden	11	9.4
Spain	9	7.7
Switzerland	5	3.2
Finland	4	2.6

The division of responsibilities between the different actors in the waste issue differs from one country to another. In some countries, such as the USA and Germany, government bodies are charged with responsibility for the spent nuclear fuel. In others the nuclear power producers bear this responsibility, directly or via jointly owned companies, such as in Sweden and Finland.

Finland is the country that has come the farthest in the siting of a geological repository. The technology is based on the Swedish KBS-3 method. During the spring of 2001, the Finnish government is expected to make a decision in principle as to whether Olkiluoto (see section 9.6) is a suitable site for the deep repository. Other countries where siting is in progress are the USA, France and Sweden.

4.8.1 Reprocessing

Reprocessing on an industrial scale takes place today primarily at the plants in La Hague in France, Sellafield in the UK and Mayak in Russia. Foreign fuel from Belgium, the Netherlands, Switzerland, Germany and Japan is reprocessed in La Hague. The two latter countries also use Sellafield. Japan has a demonstration plant in Tokai. It was closed in 1997 after an accident, but operation was resumed on a trial basis in the summer of 2000. A full-scale plant is being built and is expected to be ready to go on line in 2005.

The trend in Europe is to abandon reprocessing in favour of direct disposal of spent nuclear fuel in geological formations. Falling world market prices for uranium have made reprocessing unprofitable. Nor is it profitable to use MOX fuel today.

This trend will probably lead to a decrease in the relative portion of spent fuel that is reprocessed. Those countries that remain committed to reprocessing do so to obtain greater flexibility in their nuclear fuel supply. They hope to be able to use the energy raw material in new advanced reactor systems in the future.

4.8.2 Transmutation

In order for transmutation to be applied on an industrial scale, new reprocessing and reactor technology must be developed, which requires large inputs of both time and money. This is something for which only large countries or the EU have the means. At present there are national research programmes for transmutation in France and Japan. The EU's programme is limited to some background research and development. In recent years, however, work on accelerator-driven systems has increased.

CERN

European Organization for Nuclear Research in Geneva

A high-powered accelerator that will be able to be used for transmutation of long-lived waste is being developed in the USA. Smaller research programmes are being conducted at the CERN European research centre in Geneva as well as in the Netherlands, Sweden, Germany, Spain, China and India. Spain has, however, announced increased investment in the technology in its latest research plan.

4.8.3 Geological disposal

A general tendency is that research on geological disposal in the different countries has left the stage of general knowledge buildup and method development and entered a phase of more applied research and development.

Type of bedrock

It is possible to build safe repositories in a variety of geological formations, for example clay, salt, granite or volcanic rocks. Underground laboratories have been built in all of these types of formations. The choice of bedrock is governed by availability in each country.

Figure 4-9. *Yucca Mountain in the Nevada desert is the planned site for disposal of the USA's spent nuclear fuel.*

Countries such as France, Spain and Switzerland are exploring the possibility of building deep repositories in different types of clay formations. It is mainly the capacity of the clay to retain radioactive substances and prevent water from entering that makes it suitable for disposal of spent nuclear fuel or other HLW. Another suitable property is that the clay is plastic, which enables it to absorb movements in the surrounding medium.

Salt is also a plastic material. The absence of groundwater and fractures in salt formations means that transport of radionuclides is very slow. The world's first final repository for long-lived waste has been built in a salt formation. It is the WIPP plant in the USA, where waste from the nuclear weapons programme is disposed of. In Germany, a salt dome has been singled out as a possible disposal site for spent nuclear fuel and HLW from reprocessing. Spain has also investigated salt formations.

WIPP
Waste Isolation Pilot Plant

Countries such as Sweden, Canada and Finland are planning to build their final repositories in granite. Sweden, Canada and Switzerland have built underground laboratories. A search for a suitable granite formation for building such a laboratory is under way in France. The biggest difference compared with repositories built in clay or salt is that granite repositories require a buffer of clay that is able to absorb small movements in the rock and prevent water flow around the canisters.

Tuff
Rock type consisting of compacted volcanic sediments

The USA plans to build its final repository in a tuff formation, see Figure 4-9. The repository is located above the groundwater table. If the site can be shown to be suitable, the USDOE will recommend that a final repository be built there in 2001. A licence application will be submitted to the NRC the following year. According to current plans, the repository could be operational by 2010 at the earliest.

USDOE
US Department of Energy

NRC
Nuclear Regulatory Commission

Choice of site

Russia

A programme is under way in Russia with a general siting study to find suitable areas for geological repositories. Investigations are being conducted on sites where large quantities of radioactive waste are being stored. Both vitrified and liquid waste will be deposited at a depth of four kilometres. Since 1972, Russia has been injecting high-level liquid waste into rock at a depth of 450 metres. The method involves pumping the waste down under pressure directly out into permeable strata of sandstone, which are isolated from the surrounding environment by a thick layer of clay.

Canada

In Canada, spent nuclear fuel is planned to be disposed of in granite by means of a method very similar to the Swedish one. In 1989 the Canadian government appointed an independent panel for the purpose of analyzing the disposal concept and the chosen site. The panel found that the concept is technically valid, but that there is no popular support for carrying out the project. The panel recommended that the government establish an independent agency and change the siting process so that it is more responsive to public opinion. The government decided that responsibility for the final disposal of spent nuclear fuel rests with the producers, and that the power utilities should form a separate company to deal with all aspects of radioactive waste disposal.

France

In France, ANDRA, the state-owned company charged with the task of disposing of the HLW from reprocessing, began its geological siting studies back in the 1980s. In 1983, 30 possible sites were identified in different geological formations. Four sites were selected and investigations were begun. However, public protests grew so strong that the activities were discontinued and the law was changed.

A new law, which entered into force in 1991, pointed out that further activities would be based on the principle of voluntary participation. Preliminary investigations have now been conducted in three areas: with claystone, clay, and granite covered with sediment. In June 1999, ANDRA obtained a permit from the government to establish an underground research laboratory in claystone. Attempts are also being made to find a new site in granite. At the same time, research on long-term near-surface interim storage (supervised storage) and on transmutation is being conducted. Sufficient background material on all these alternatives shall be available by 2006 as a basis for decisions by the government and parliament on how the HLW is to be managed and disposed of.

Finland

In Finland, the Finnish power utility TVO, which owns the NPP in Olkiluoto, commenced geological siting studies. Two site investigations got under way in 1993 in three municipalities (Eurajoki, where Olkiluoto is located, Romuvaara and Kivetty). Later, the municipality of Loviisa also entered the picture. All sites are situated in granite formations. Disposal is based on the KBS-3 method.

Posiva
Finnish equivalent of SKB

The geological investigations were supplemented by a programme for EIAs and a safety assessment. These were submitted to the government in 1998. The safety assessment showed that all four of the sites satisfied the safety requirements. In May of 1999, Posiva signed a contract with the municipality of Eurajoki in which they promised to build a repository in connection with the NPP in Olkiluoto, provided permits were obtained from the government and the regulatory authorities. Then Posiva submitted an application with an EIS for each of the four sites, but singled out Olkiluoto as a priority candidate.

In order for construction to begin on the final repository, a decision in principle is required from the Finnish government. The prerequisites for such a decision to be positive are that both STUK (the Finnish Radiation and Nuclear Safety Authority) and the concerned municipality give their approval. The parliament must then approve the government's decision. The municipal council in Eurajoki has said yes to the final repository. At the same time, STUK found that there are no safety-related obstacles in the way of a decision in principle by the government. The decision should have been made some time during 2000, but has been delayed due to the fact that an individual in the municipality of Eurajoki has appealed the municipal decision. The Superior Administrative Court found in November 2000 that there is no legal basis for the appeal. The government's decision in principle is expected in December 2000, and the parliament's decision in the spring of 2001. If it is positive, a shaft will be excavated down to a depth of approximately 500 metres to start with. The purpose is to further confirm the data obtained in the site investigations. The work will take between three and four years and will be commenced in 2003, according to the plans. The actual deposition process can begin in 2020.

Spain

Spain intends to dispose of its spent nuclear fuel and the HLW from reprocessing in some geological formation: granite, clay or salt. A programme for finding a suitable site started in 1986 with the aim of commissioning a repository in 2025. The siting programme consisted of general siting studies and feasibility studies, from which 30 sites were selected.

In 1996, the Spanish implementing organization Enresa announced that the date of commissioning of the repository had been postponed indefinitely. Enresa's most recent general plan postpones all siting work until after 2010. Special research efforts will be launched on both reprocessing/transmutation and direct disposal. A geological repository can be commissioned between 2035 and 2040 at the earliest.

United Kingdom

The site selection process in the UK has been discontinued. In March 1999, a committee from the House of Lords presented the results of an inquiry in which it was concluded that the policy pursued to date is too fragmented, and that a new organization should be established and charged with the task of finding a broadly acceptable solution.

Germany

In Germany, the policy since the early 1960s has been that all types of radioactive waste should be disposed of deep underground. At the same time, general siting studies were begun to find suitable geological formations. Interest was focused at an early stage on salt. In 1977, the state government in Lower Saxony designated the salt dome in Gorleben as a site for a final repository.

The geological investigation of the salt dome in Gorleben was to be finished by 2003. It was to be followed by a statement that the salt dome was a suitable site for a repository and by a safety assessment. However, an agreement between four of the power utilities and the government has led to a delay of the programme. The investigations in Gorleben have been discontinued and postponed for between three and ten years. According to the agreement, certain unanswered questions regarding future planning and long-term safety first have to be cleared up.

4.8.5 An international repository?

Some small countries such as Lithuania, Belgium and Switzerland sometimes raise the question of building an international repository. There are also companies that have taken the initiative to such a joint project. An important basic principle is voluntary participation, i.e. no country can be forced to accept waste from other countries.

The countries that support the idea of an international repository generally have small waste quantities themselves. By joining together with other nations in a similar position, they hope to make better use of their combined intellectual and financial resources. An international repository is also seen as a way for a country with no suitable geological formations within its boundaries to find a safe solution to its waste problem.

Proposals for international repositories have met with little response in most countries. There is no interest in such a solution in Sweden.

5 Methods for geological disposal

A deep repository according to the KBS-3 method has been the main alternative for SKB's research and development work for twenty years and therefore serves as a natural reference in a comparison with other proposed methods for geological disposal.

Although an evaluation of alternative methods for geological disposal against requirements in acts and ordinances shows that the alternatives to KBS-3 can have advantages in certain respects, KBS-3 emerges as the best method in an overall assessment.

For the alternative Very Deep Holes, SKB has, in accordance with the Government decision regarding RD&D-Programme 98, described the thrust and scope of the research and development programme that would be required for a comparison with KBS-3, based on equivalent data. SKB finds that it is unclear whether this alternative can be implemented in practice in such a way that the safety requirements can be satisfied. Even if this should prove possible, the Very Deep Holes alternative does not offer overall safety advantages over KBS-3 that could justify the time and costs for carrying out the research and development programme.

Different strategies for managing spent nuclear fuel were evaluated in the first stage of the system analysis. The survey showed that geological disposal is the alternative that best satisfies the stipulated requirements. In this second stage, alternative systems for geological disposal are compared.

To facilitate a comparison, a more detailed target specification has been formulated. A brief description of each system is followed by an evaluation of the possibilities of finding a suitable site, building and operating the facility, and achieving good long-term post-closure safety. The analysis also includes an assessment of time and costs for developing and implementing the alternatives, as well as the possibilities of retrieving the spent nuclear fuel.

5.1 Requirements on system for geological disposal

The following target specification is an interpretation of what the implications the requirements in laws and regulations as well as international agreements may have for geological disposal. The results of studies by the OECD/NEA /5-1/ have been taken into account. The specification is also based on viewpoints that have emerged during the regulatory review of the RD&D programmes and statements from regulatory authorities and the Government.

OECD
Organization for Economic Cooperation and Development

NEA
Nuclear Energy Agency

SKI's proposed regulations concerning safety in the final disposal of nuclear waste, which contain specific requirements for final disposal in rock, have been taken into account in formulating safety requirements for geological disposal.

5.1.1 Overall requirements

Of the overall requirements, only the requirement of not imposing burdens on future generations can provide more precise grounds for comparison of systems for geological disposal. One interpretation of the requirement is that the time it takes to develop and implement the disposal method should not be too long.

The ethical aspects of when and how the waste should be disposed of has been discussed within the OECD/NEA /5-1/, by KASAM /5-2/, and within a national EIA forum in the nuclear waste field /5-3, 4/. On the one hand, burdens should not be imposed on future generations. On the other hand, the current generation should not restrict the freedom of action of future generations. As regards systems for geological disposal of spent nuclear fuel, this means that a closed repository should not require active maintenance or surveillance. If future generations so wish, it should be possible to retrieve the emplaced fuel.

5.1.2 Environmental requirements

The Environmental Code lays down requirements on good management of materials and energy, as well as of land and water areas. Future generations should in principle be able to use the site of the repository for anything they wish. The bedrock should not contain anything considered today to be natural resources, and the repository should be deep enough to avoid being affected by human activities on or near the surface. Furthermore, the repository should be designed to minimize material and energy consumption and environmental disruptions.

5.1.3 Safety requirements

A geological disposal system shall be safe during construction and operation and after closure. Post-closure safety shall be maintained by a passive barrier system. The barriers can have several functions that contribute towards preventing and retarding dispersal of radionuclides.

In the case of a repository deep down in the rock, this means that the bedrock should be easy to characterize in terms of properties that are essential for constructability, reliability and post-closure safety. Proven materials and engineering principles should be used to as great an extent as possible in design, construction and operation. Furthermore, the properties of the spent fuel must be taken into account so that criticality does not arise and so that heat and radiation from the fuel do not seriously degrade the barrier functions.

Deficiencies in the barrier functions must not significantly impair the safety of the repository. This means that features, events and processes (FEPs) that can influence barrier performance must be identified and their importance for long-term safety evaluated. This includes both influences that can occur during construction and operation, and influences that can occur after the repository has been closed and far into the future.

5.1.4 Radiation protection requirements

Radiation doses shall be limited as far as possible with respect to technology, economics and society. The entire handling chain, as well as future doses, shall be taken into account and weighed together.

During construction and operation, the system shall be optimized with respect to the radiation protection requirements by means of different technical and administrative measures.

In order to be able to calculate or set limits on future radiation doses from a closed repository, it must be possible to predict future changes in the barriers and their importance for possible releases of radioactive substances.

5.1.5 Requirements on non-proliferation of nuclear material and nuclear waste

Questions relating to safeguards for final repositories for radioactive waste and spent fuel have been discussed within the IAEA /5-5/. Ways to ensure that fissionable material is not diverted for unauthorized purposes shall be considered in conjunction with repository design, siting and operation. The IAEA believes that a closed repository also needs safeguards.

The smallest unit that can be monitored changes gradually during spent fuel management. Up until when the spent fuel has been encapsulated, it is possible to verify individual fuel assemblies and individual fuel rods. After that the canister is the smallest surveillable unit. When a deposition area has been closed, it is no longer possible to monitor individual canisters. Attention must then be concentrated on ensuring that canisters are not taken out of the repository. When the repository has been closed, safeguards shall ensure that it is not opened again or accessed via adjacent rock facilities.

IAEA

International Atomic Energy Agency, in charge of international surveillance of fissionable material (safeguards)

5.2 Systems for geological disposal

The main facility that determines the design of the facilities in a system for geological disposal is the repository itself. The comparison of systems for geological disposal is therefore focused on alternative methods for designing a repository. The technical solutions for a repository in crystalline rock that have been studied in Sweden are KBS-3, Very Long Holes, WP-Cave and Very Deep Holes.

A geological repository has two safety functions. The first is to isolate the spent nuclear fuel. The second is to delay the release of radionuclides if this isolation should fail in any respect. Isolation is achieved by encapsulating the spent fuel in tightly sealed canisters. By "retardation" is meant that the time it takes for radionuclides to be transported from the repository to the ground surface is so long that the radioactivity decays completely or to low levels before reaching man or the human environment.

The rock should provide a natural barrier that protects the engineered barriers at the same time as it retards the transport of any leaking radionuclides to the biosphere. A well-chosen site in the Swedish crystalline bedrock is expected to possess low permeability and generally low water flux. The chemical conditions at disposal depth are expected to be stable, with groundwater that is free from oxygen. It is possible to find canister materials, for example copper, that are corrosion resistant in the long term in this environment. The rock also offers a mechanically stable setting. The geological conditions provide the premises for the design of the rock facilities and the engineered barriers.

Temperature is an important factor in designing a repository. The function of the engineered barriers over time is easier to demonstrate if the highest temperatures in the repository (near the canister surface) are below boiling. The temperature in and around a canister depends on its content of radionuclides, the size of the canister and how the other engineered barriers are designed. The temperature and thermal conductivity of the surrounding rock, and the emplacement density of the canisters in the rock volume, also influence the temperature in the repository.

The disposal depth should be great enough that the changes, both natural and human-induced, we can expect on the surface do not affect the repository. Temperature and rock stresses increase with depth and the groundwater composition changes, which affects the premises for repository construction.

KBS-3

The waste is emplaced in a system of relatively short tunnels at a depth of approximately 500 metres

VLH
(Very Long Holes)

The waste is emplaced in a small number of parallel tunnels several kilometres in length

WP-Cave

The waste is emplaced in a dense array in a limited rock volume surrounded by a thick buffer. The water flux is limited by engineering measures

VDH
(Very Deep Holes)

The waste is emplaced in boreholes several thousand metres in depth

The disposal depth in KBS-3, Very Long Holes and WP-Cave is no more than about 700 metres. These repositories are built in tunnel systems, of which there is very wide experience in Sweden. In the fourth alternative – Very Deep Holes – the disposal depth is much greater, several thousand metres.

5.2.1 KBS-3

KBS-3 is SKB's main alternative for management and disposal of spent nuclear fuel. Extensive background material is available in support of this alternative. KBS-3 is therefore used here as a reference for comparison of the alternatives. The abbreviation KBS stands for Kärnbränslesäkerhet = Nuclear Fuel Safety. This was the name of the project whose purpose was to demonstrate that the spent fuel could be managed and disposed of in a safe manner prior to commissioning of the Swedish NPPs. The project produced three main reports. The third of these, KBS-3, was included in the permit application for charging the Forsmark 3 and Oskarshamn 3 reactors with fuel. KBS-3 thereby gave the name to the method for disposal of spent nuclear fuel that was then proposed.

Bentonite clay

Soft clay that wells on uptake of water

In the reference design, the repository consists of tunnels at a depth of about 500 metres. A ramp and/or shaft leads from the surface down to a disposal area with transport and deposition tunnels. Canisters with spent nuclear fuel are placed in vertical holes in the floors of the deposition tunnels and embedded in a buffer of bentonite clay. The placement of the deposition tunnels, as well as the spacing of the deposition holes, are determined with reference to the requirement that the temperature on the canister surface may not exceed 100°C. Isolation and retardation in a KBS-3 repository are achieved by a system of barriers, see Figure 5-1.

Isolation is achieved directly by the copper canister. The buffer contributes indirectly to isolation by keeping the canister in place and preventing corrosive substances from coming into contact with the canister. The rock also contributes to isolation by offering a stable chemical and mechanical environment for the canisters and the buffer.

All barriers contribute to the repository's retarding function. Even a partially damaged copper canister can effectively contribute to retardation by impeding inflow and outflow of water. The clay buffer has the capacity to retain many of the radionuclides with the greatest long-term radiotoxicity, since they adhere to the surfaces of the clay particles. The rock contributes by virtue of low water flux. Furthermore, radionuclides adhere to fracture surfaces and/or penetrate into microfractures with stagnant water. The fuel itself also makes an important contribution to retardation, since it consists of a poorly soluble ceramic material. Furthermore, many of the long-lived nuclides are poorly soluble in water.

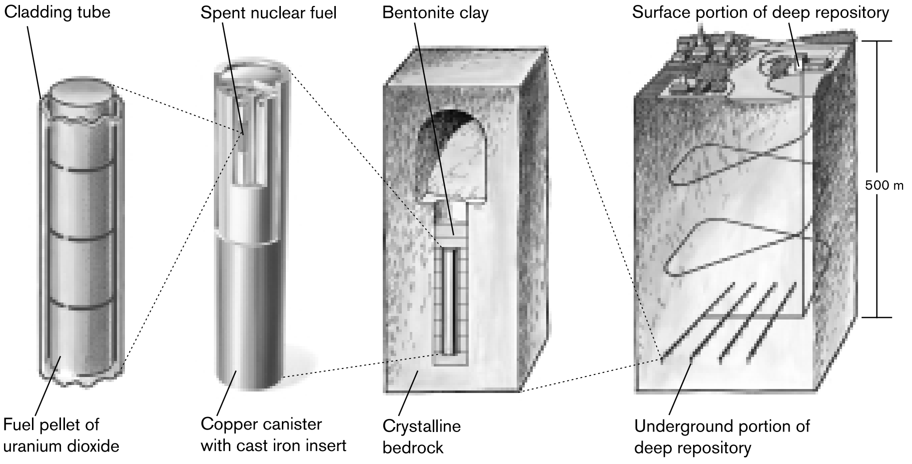


Figure 5-1. *Geological disposal according to the KBS-3 method.*

A number of system variants are possible as regards design of canister, backfill material and repository. The freedom of choice that exists in these respects is dealt with in section 6.4.

5.2.2 Very Long Holes - VLH

Very Long Holes is a method that is designed with a view towards siting of the repository in the bedrock beneath the sea /5-6/. Safety principles, barriers and materials are the same as in KBS-3, but the technical design is different. The repository consists of three parallel tunnels with a length of about five kilometres at a depth of about 400–700 metres. Canisters of spent nuclear fuel are emplaced horizontally directly in the deposition tunnels and embedded in a buffer of bentonite clay, see Figure 5-2. The main differences from KBS-3 are the horizontal emplacement position and the larger canister.

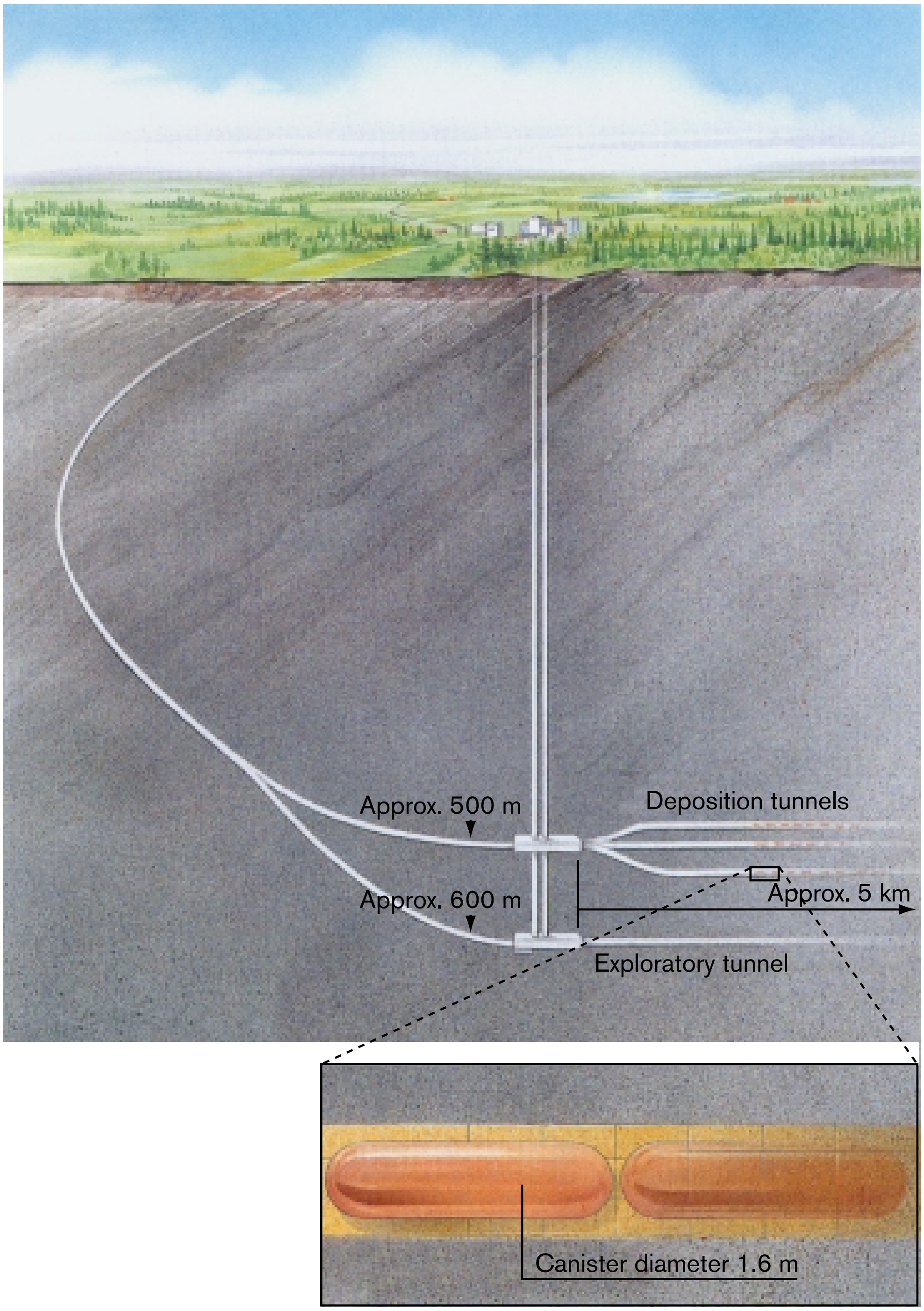


Figure 5-2. *Geological disposal in Very Long Holes.*

5.2.3 WP-Cave

WP-Cave is a proposed repository design developed by the company WP-system and submitted to SKB in the 1980s. The purpose of WP-Cave is to reduce dependency on the properties of the rock by means of engineering measures, facilitating siting.

The concept entails emplacing encapsulated spent fuel in a dense array in a limited rock volume surrounded by a 5-metre-thick buffer. The disposal volume consists of several storeys of tunnels emanating from a central shaft, roughly like the spokes of a wheel. The buffer is in turn surrounded by a hydraulic cage, a system of tunnels and boreholes that divert the groundwater around the disposal volume. About 9–10 disposal units of the type shown in Figure 5-3 are needed to hold the fuel from 40 years of operation of the NPPs /5-7/.

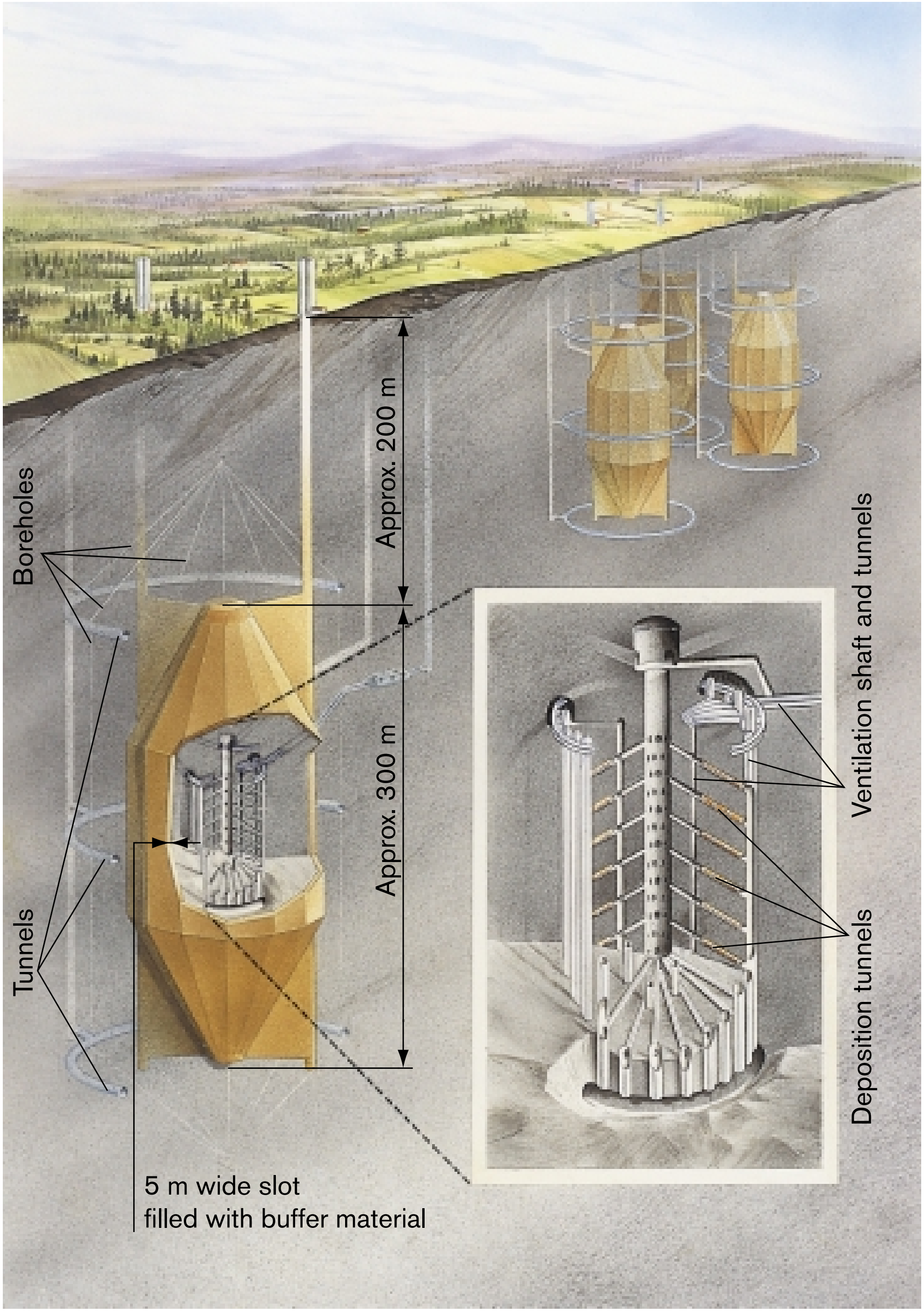


Figure 5-3. *Geological disposal according to the WP-Cave method.*

The concentration of the fuel in a smaller rock volume leads to high temperatures. To keep the temperature from getting too high, the repository must be kept open for air cooling for the first 100 years or so. The repository and its cooling also enable newly discharged fuel to be emplaced in the repository, obviating the need for an interim storage facility.

Safety is based primarily on the engineered barriers. In the proposed design, the canisters are made of steel. If the repository's isolation is broken, the backfill material in the deposition tunnels and the rock surrounding the canisters comprise the first barrier to radionuclide transport. The buffer obstructs transport of radionuclides out from the disposal volume, while the hydraulic cage reduces the water flux in the repository.

5.2.4 Very Deep Holes - VDH

VDH is the alternative that differs the most from KBS-3. At great depths, several thousand metres, the water is very saline and the rock is assumed to have low permeability. The saline water is assumed to be in principle stagnant for very long periods of time, up to millions of years. The low permeability and high salinity contribute towards very low water exchange with the water surface. This is a potential advantage of very deep repositories over shallower repositories. Great disposal depth also makes human intrusion more difficult.

At great depth, however, rock stresses and temperatures are high. These properties, plus the high salinity, creates difficulties for a siting of a repository for spent nuclear fuel at great depth. Excavation of tunnels is not a realistic option to get down to depths of several thousand metres. A repository design with Very Deep Holes would seem to be the only feasible alternative. This alternative has been investigated by SKB in several studies since the end of the 1980s /5-8, 9/.

In the reference design, the repository consists of approximately 40 boreholes, each around 4,000 metres deep. The distance between the boreholes is approximately 500 metres. This spacing is determined by the heat output of the fuel and the fact that the boreholes are allowed to deviate a degree or two from the vertical. The borehole diameter is 1.4 metres down to a depth of about 2,000 metres and then 0.8 metre /5-10/. The canister in the reference design is made of titanium with concrete fill, but other alternatives are also possible. The canisters are deposited on top of one another in the borehole at a depth of between 2,000 and 4,000 metres, and embedded in a buffer whose primary purpose is to fix the canister in relation to the surrounding rock. The proposed design is shown in Figure 5-4.

Like other concepts, the method has two safety functions: isolation and retardation. Isolation is achieved by means of a tightly sealed canister designed to remain intact for at least 1,000 years. Due to high rock stresses and salinities, it cannot be assumed that the canister and buffer will remain intact for a longer time. The most important safety function is therefore to retard the transport of radionuclides to the ground surface. Retardation is mainly achieved by the rock and the great disposal depth. The rock thereby comprises the principal barrier.

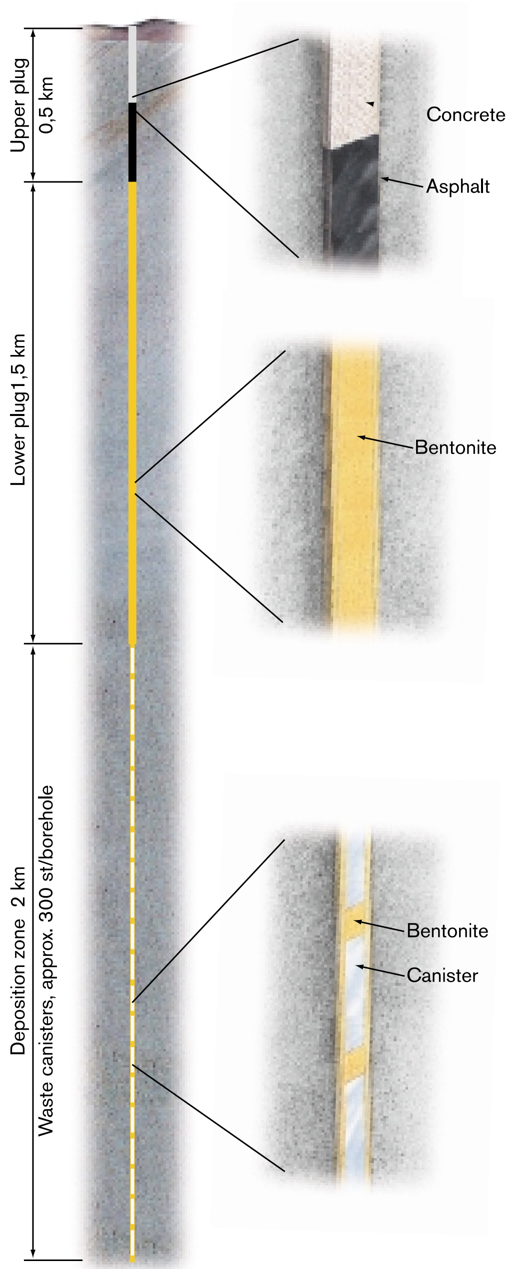


***Figure 5-4**. Geological disposal in deep boreholes.*

5.3 Evaluation against requirements

The alternatives for geological disposal have been compared with respect to the requirements formulated in section 5.1.

5.3.1 Compliance with overall requirements

The requirement of not imposing burdens on future generations was interpreted in section 5.1 as meaning that the time it takes to develop and implement the disposal method should not be too long. A broader interpretation of this requirement is that future generations shall be able to retrieve the emplaced fuel, if they so desire.

Time for development

KBS-3 is well-developed and ready for moving into the implementation phase. VLH is so similar to KBS-3 in many respects that such a repository is also judged to be able to be realized in a relatively short time. WP-Cave requires further knowledge accumulation to ascertain whether long-term safety can be guaranteed. VDH requires technology development for site investigation and implementation, see section 5.4. Furthermore, knowledge accumulation is needed to analyze long-term safety and identify factors of importance for safety that must be clarified in the site investigation. It cannot be taken for granted that the time devoted to knowledge accumulation and technology development will lead to safe and feasible systems.

Retrieval

As long as the repository is open, retrieval of single canisters is simpler for KBS-3 and WP-Cave than for the other two alternatives, since the canisters have been deposited one by one in the first case and two by two in the second. More or less the same equipment can be used in both alternatives.

In VLH and VDH it is necessary to lift out all canisters that have been deposited after the canister to be retrieved. Special equipment must be developed for retrieval.

After closure the tunnel alternatives (KBS-3, VLH and WP-Cave) are judged to be roughly equivalent with respect to the possibilities of retrieval. Retrieval from VDH is more difficult technically and from a radiation safety point of view.

5.3.2 Environmental impact

The alternatives for geological disposal have been compared in terms of restrictions on future use of the repository site and environmental impact during the construction and operating phases.

Restrictions on future use

When repositories based on KBS-3, VLH or WP-Cave have been closed and sealed, deep drilling and construction of large rock facilities at great depth are not suitable activities. Nor are such activities likely to be suitable near a VDH repository, since they can harm the borehole plugs. Judging by present-day experience, the likelihood of someone inadvertently drilling through a canister and being exposed to the fuel is greater for the tunnel alternatives than for VDH. This is because boreholes to great depths are very unusual today. All factors considered, VDH may, thanks to the great disposal depth, have advantages in terms of restrictions on future use of the site.

Land and groundwater

The land requirement for the surface portion of the deep repository is smallest for a VLH repository (approx. 0.2 km^2) and slightly greater for KBS-3 (approx. 0.3 km^2). WP-Cave requires a larger land area. A VDH repository covers the most land, since each borehole requires a work area and the boreholes have to be spread out over a relatively large area.

The drawdown of the groundwater table is greatest for WP-Cave, due to the greater extent of the underground portion of the repository and the long open period. VDH does not lead to any drawdown of the groundwater table.

Consumption of natural resources

WP-Cave requires the excavation of much greater volumes of rock and bentonite than other methods. The excavated rock volume is least in VDH. Consumption of copper is roughly of the same magnitude for KBS-3, VLH and VDH: 35,000–45,000 tonnes. Data are lacking for WP-Cave. Furthermore, large volumes of concrete, sand etc. are used in all tunnel repositories.

5.3.3 Safety

The requirements call for high safety both during construction and operation of the repository and after closure. The alternatives have been compared with regard to opportunities to characterize the bedrock and its properties of importance for safety, and opportunities to use proven materials and design principles. Moreover, barrier functions and opportunities to evaluate them both now and in the future have been set up as a comparison ground.

Characterization of the bedrock

Opportunities to characterize the bedrock and those properties that are essential for constructability, reliability and long-term safety are good for the tunnel alternatives. Investigations down to a depth of approximately 5,000 metres are necessary for VDH. Investigation methods are not available and must therefore be developed. A programme must be developed for establishing which properties are to be measured and for defining disqualifying factors. Compared with the other methods, a much larger area must be investigated to a much greater depth. The underground portion of a repository based on VDH occupies an area of approximately 7–10 square kilometres and a depth of approximately 4,000 metres, as compared to 1–3 square kilometres and 400–700 metres, respectively, for the tunnel alternatives.

Design and construction

The repositories in tunnel systems can utilize proven design principles in construction of the rock facility and the engineered barriers. VDH requires development of new technology for construction and for canister deposition. KBS-3 and VLH have a flexible layout that can be progressively adapted to information that emerges during construction. In the case of WP-Cave and VDH, it is not deemed possible to adapt the layout to information that emerges after the start of construction. In the worst cases, the disposal area/borehole must be abandoned.

Reliability

Disturbances and accidents can occur when canisters are moved, lifted and otherwise handled. If accidents or disturbances should occur, it may be more difficult to arrange good radiation protection in VLH and WP-Cave, due to a lack of space in the deposition tunnels. In VDH it is difficult to inspect the consequences of an accident, for example to see whether the canister has ruptured or not. This means that it may be more difficult to identify and adopt suitable measures.

In VDH, visual inspection of the emplaced canisters is not possible. Deposition takes place at least two kilometres below the ground surface in a pressurized deposition fluid. It may also be difficult to design equipment that permits verification of good deposition results.

In the event of fire or accident in VLH, evacuation is more difficult than in a KBS-3 repository. Operation of a KBS-3 repository is simpler and safer than operation of a VLH repository.

Long-term safety

Regardless of the design of a final repository, every assessment of long-term performance is associated with uncertainties. It must be possible to evaluate these uncertainties and show that they do not affect the conclusion that the repository satisfies the safety requirements. This is a fundamental requirement to obtain a permit to build a final repository.

For KBS-3, the impact of realistic geological changes on engineered barriers has been analyzed in several safety assessments /5-11, 12, 13/. The analyses show that the engineered barriers, together with the rock, provide adequate safety both now and far into the future. This is true even in the event of deficiencies in one of the barriers. The uncertainties that are associated with the long-term integrity and function of each of the barriers are compensated by the fact that the barriers complement each other, so that their combined function can be considered sufficiently good.

A VLH repository is deemed to be equivalent to a KBS-3-type repository in terms of safety functions and barriers.

In WP-Cave, the hydraulic cage and the buffer provide a rock volume with a suitable environment to dispose of the spent fuel. The long-term function of the structures in WP-Cave is judged to be difficult to demonstrate /5-14/. The high temperatures in WP-Cave also entail increased uncertainties surrounding several processes of importance for safety.

For VDH, it is not deemed possible to design a buffer and a canister whose function will last for a long time. The stresses to which the canister are subjected during deposition, when it is pressed through a deposition fluid down in the 4,000-metre-deep borehole, are such that it must be assumed in a safety assessment that a considerable number of canisters have initial defects. It must be shown for the initial 1,000 years that the elevated temperature at depth does not cause an unacceptable flow of radionuclides up along the borehole. In a longer time perspective, the rock and the great depth alone must be shown to comprise an adequate barrier for maintaining safety. This is not possible on the basis of present-day knowledge, and may be difficult even after completion of a major research programme.

5.3.4 Radiation protection

The radiation doses shall be kept as low as possible during the entire handling chain and after closure. In order to calculate future doses from a closed deep repository, it must be possible to describe changes in the rock and the engineered barriers in a long time perspective.

Construction and operation

During construction and operation of the tunnel alternatives, the construction personnel are exposed to radon from the bedrock. This does not occur in VDH.

In normal operation, there is no release of activity from the waste in any of the alternatives, and the dose to personnel is judged to be low. Not even in the event of severe accidents are the tunnel alternatives expected to give rise to any release of radioactivity. This might, however, occur in connection with VDH.

If disturbances occur in the handling of the fuel during deposition, it may be more difficult to provide radiation protection for VLH and WP-Cave than for KBS-3. In the VDH alternative, it should not be difficult to provide radiation protection in the event of disturbances, provided the canister has not failed.

Future dose load

Future radiation doses from a KBS-3 repository have been calculated for different scenarios, most recently in the SR 97 safety assessment, see Chapter 7. The calculated doses satisfy the radiation protection requirements with a wide margin.

A VLH repository bears many similarities to KBS-3. Even though no safety assessment has been performed, this method can also be expected to satisfy the radiation protection requirements.

It may be difficult to satisfy the radiation protection requirements for WP-Cave /5-14/. The high temperatures make it difficult to assess the consequences of certain processes of importance for safety. It may be difficult to demonstrate the performance of the cage and the buffer over long time spans and in the event of ice ages. The large quantity of fuel that is enclosed by one and the same buffer entails a risk if the function of the buffer should be impaired and several canisters should leak.

No safety assessment has been conducted for VDH. Knowledge of the properties of the rock at great depth and the evolution of the engineered barriers over a long time is not sufficient. The high temperatures and high salinity entail uncertainties with regard to fuel dissolution and the properties of the radionuclides.

5.3.5 Non-proliferation of nuclear material and nuclear waste

Opportunities for arranging safeguards are judged to be good for all the methods. In the case of VDH, the more extensive handling above ground and the lighter canister may be a disadvantage during operation. After closure, safeguards can be arranged in a similar manner for all methods.

None of the methods makes it impossible to get at the fuel, but great efforts are required. In the tunnel alternatives, tunnels or shafts have to be driven down into the repository, while in VDH the plugs have to be bored out and the canisters lifted up. The latter is judged to be more difficult and risky than the former.

5.3.6 Costs

The survey of different alternatives is not complete without a comparison of the costs of implementing them. In the PASS study from 1992 /5-9/, the costs of encapsulation and final disposal were compared for KBS-3, VLH and VDH. The comparison was made according to the principles that are used in the annual calculations of the costs for management of the waste from nuclear power that underlie the Government's decision on annual charges to be paid to the Nuclear Waste Fund. The calculations showed that the total costs for encapsulation and deposition for KBS-3 and VLH were approximately equal, while the costs for VDH were considerably higher than for KBS-3 (approximately 50–150 percent higher, depending on choice of technology).

PASS
Project on Alternative Systems Study

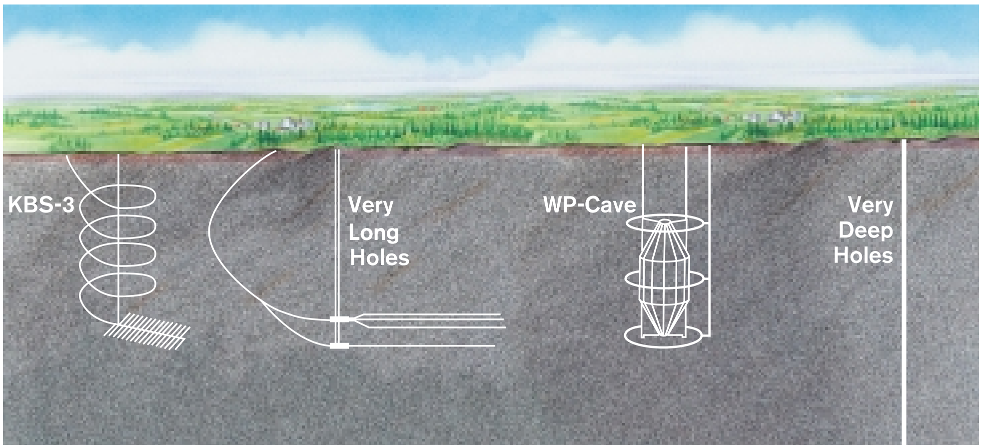
Another study from 1989 /5-14/ arrived at the conclusion that the costs for encapsulation and disposal of spent nuclear fuel based on the WP-Cave concept would be more than 50 percent higher than for the equivalent based on the KBS-3 method.

The comparisons show, even taking into account the uncertainties in the calculations, that the alternatives to a final repository based on the KBS-3 method do not have any cost advantages compared with the KBS-3 repository.

5.3.7 Overall assessment

The KBS-3 method is well-developed and ready for moving into the implementation phase. The comparison with other alternatives is summarized in Figure 5-5. Radiation protection and safety in particular, both long-term and during operation, are the factors that put KBS-3 ahead of the alternatives.

VLH is more or less equivalent to KBS-3 and has some environmental advantages. However, KBS-3 is deemed to offer better safety during operation. WP-Cave has clear disadvantages compared with KBS-3.



Requirement/ Comparison ground	KBS-3	VLH	WP-Cave	VDH
Not impose burdens on future generations	=	-	-	-
Environmental requirements	=	+	-	+
Safety requirements	=	-	-	-
Radiation protection requirements	=	=	-	-
Safeguards	=	=	=	+
Costs	=	=	-	-

= meets requirements as well as KBS-3
\+ has advantages compared with KBS-3
\- has disadvantages compared with KBS-3

Figure 5-5. *SKB's assessment of different methods for geological disposal.*

In order to settle on a technology and design and assess the safety of the alternatives WP-Cave and VDH, extensive knowledge accumulation and technology development are required. Even if such efforts were to be successful, an overall assessment does not show these alternatives to be more interesting. Both alternatives are associated with considerable uncertainty regarding if and when repositories could be built. There is thereby a risk that disposal of the spent fuel will be a question for future generations.

5.4 Research and development programme for VDH

In its decision regarding RD&D-Programme 98, the Government writes:

> "Furthermore, the alternative Very Deep Holes (disposal in boreholes at a depth of several kilometres) should be explored with an emphasis on the scope and content of the research and development programme that is needed for a comparison of the Very Deep Holes alternative with the so-called KBS-3 method on equivalent grounds."

The VDH alternative was evaluated in PASS (Project on Alternative Systems Study) /5-9/. The study found that there was less knowledge of the VDH disposal system than of any other of the systems then compared (WP-Cave was not included in the study). The results from PASS and a later compilation of geological conditions at great depth /5-15/, have served as a basis for the recently completed study of a research and development programme for the VDH disposal concept /5-16/.

5.4.1 Content of the programme

The study deals with the state of knowledge and the need for research and development within:

- geoscience,
- drilling and deposition technology,
- engineered barriers and safety assessment.

Furthermore, the study presents timetables and costs.

In order to get an answer to the geoscientific questions, pilot holes must be drilled to a depth of at least four kilometres on three selected sites. On these sites, equipment and methods for measurement and investigation are developed. Active participation in international deep drilling projects is imperative.

On one of the sites, efforts are continued to develop and demonstrate technology for drilling, deposition and retrieval. For this purpose it is necessary to drill at least two deep holes with full deposition diameter (0.8 metre).

The question of the engineered barriers and their function is closely connected to the assessment of long-term safety. High groundwater pressures, mechanical loads, temperatures and salinities impose other requirements on the engineered barriers than those that apply to a KBS-3 repository. Research and development is required to design the canister and select material for the buffer around the canister. Fuel dissolution at high temperatures and salinities requires development of improved analysis methods and knowledge of how radionuclides occur under such conditions.

It should be possible to assess long-term safety for disposal in Very Deep Holes using largely the same methodology as that used for a KBS-3 repository. One important difference in the premises is that in VDH, no long-term isolating function can be ascribed to the canister and the buffer. In SKB's judgement, the assessment must assume that canisters are damaged and leak initially, and that all canisters have failed after on the order of a thousand years.

The study contains a systematic comparison of the state of knowledge and methods for VDH and KBS-3. As expected, it shows that for KBS-3, known and proven methods are available in most respects, whereas for VDH knowledge and methods are lacking in most respects. The comparison has been used to identify R&D needs and to raise the state of knowledge for VDH to the same level as for KBS-3.

5.4.2 Overview of premises

If the programme were to be carried out, the premises in the PASS report would also have to be re-examined. A possible variant of the concept is to change the depth of the hole. This requires better knowledge of how the properties of the rock mass change with depth. Then it may be possible to justify reducing the depth to e.g. 2.5 kilometres with a 1.25-kilometre plug zone and a 1.25-kilometre deposition zone. The diameter of the deposition hole would then also be re-examined.

If it proves difficult to achieve sufficient knowledge regarding the function of the rock, it might be possible to compensate for this by increasing the depth of the holes, for example to approximately six kilometres. Increasing depth would also lead to greater technical difficulties, however, for example with regard to borehole stability.

Another premise that may need to be re-examined is the choice of buffer material. Since the primary purpose of the buffer is to keep the canisters in place, it is not obvious that bentonite is the best choice, particularly if it should turn out that the salinity of the groundwater exceeds 10 percent.

5.4.3 Time and costs

The study shows that it would take about 30 years to carry out the programme. The geoscientific research work dominates the timetable.

The cost has been estimated at around SEK four billion. The biggest cost items are geoscientific research and development (approx. SEK 0.5 bn), investigations in a rock laboratory with two full-sized 4,000-metre-deep boreholes (approx. SEK 1.4 bn) and research and development of engineered barriers (approx. SEK 0.5 bn).

Development of drilling technology (estimated cost SEK 130 million) involves great uncertainties and could further prolong the total time and increase the cost.

5.4.4 SKB's assessment

Essential uncertainties must be cleared up in order for a VDH disposal to be compared with KBS-3 on equivalent grounds. The uncertainties mainly pertain to rock and groundwater conditions in the deep bedrock and the technology for deposition and backfilling of the holes.

SKB plans to continue keeping track of international development of VDH

The comparative analysis (see sections 5.1–5.3) shows that there is no evidence that a VDH repository, even if it can be shown to live up to all requirements, would enhance the safety or lower the costs of spent nuclear fuel disposal. SKB therefore does not plan to carry out the RD&D programme for VDH, but instead to concentrate its resources on realizing a repository based on the KBS-3 method in a relatively near future. SKB will continue to keep track of international development in the field.

6 Deep disposal system based on KBS-3

In order to fully implement the KBS-3 method, two nuclear installations need to be built: an encapsulation plant and a deep repository. A factory for fabrication of canisters and additions to the transportation system are also needed.

The deep repository consists of a system of multiple barriers based on natural, stable materials. This provides good long-term safety while preserving the possibility for future generations to retrieve the waste or modify the repository conditions, should they so desire.

Established principles and experience from existing facilities in Sweden and abroad can be applied to ensure safety during operation of the facilities. The radiation doses to personnel and the surrounding environment are expected to be low from all steps in the process.

There is still freedom of choice before the design of the system has to be finalized. Decisions can be made progressively based on knowledge that emerges from SKB's work and from similar work in other countries.

Since the early 1980s, the main alternative for ultimate disposal of spent nuclear fuel from the Swedish NPPs has been disposal at a depth of approximately 500 metres in the bedrock in accordance with the KBS-3 method, see Figure 6-1. The background and reasons for the choice of this strategy were described in Chapters 4 and 5.

This chapter summarizes the system analysis of the main alternative /6-1/. Compared with an equivalent analysis /6-2/ in RD&D-Programme 98, a clearer limitation has been made to the facilities that are needed for management and disposal of spent nuclear fuel.

The purpose of the system analysis of the main alternative is to show how the system can be designed to satisfy the safety, radiation protection and environmental requirements. The system analysis is an ongoing activity which will lead to a report in conjunction with the submission of a siting application. The description here can therefore be seen as a progress report on how far SKB has come and what still remains to be done in designing the system.

The deep disposal system
- CLAB
- Encapsulation plant
- Canister factory
- Deep repository
- Transportation system

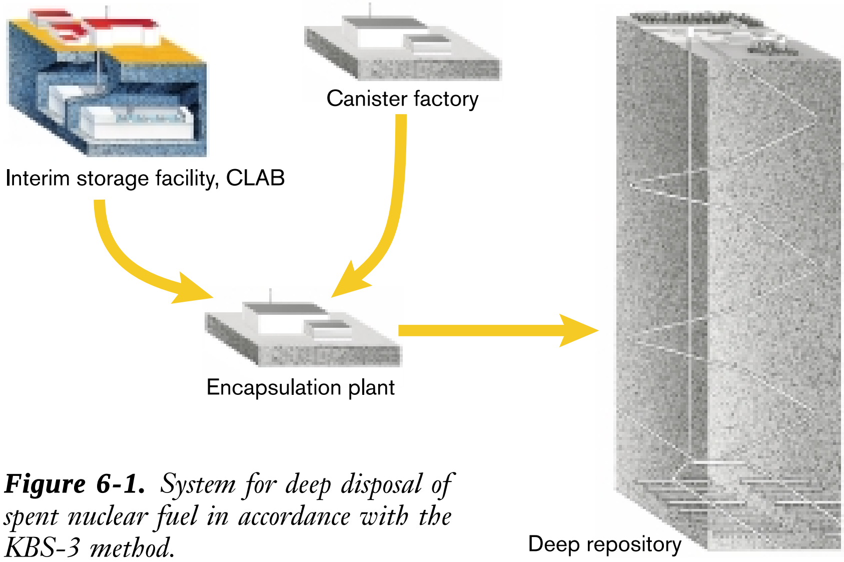


Figure 6-1. *System for deep disposal of spent nuclear fuel in accordance with the KBS-3 method.*

6.1 System description

Principles for design of a repository in accordance with the KBS-3 method were described in section 5.2. A system of interacting facilities is required in order to encapsulate and deposit the spent nuclear fuel in accordance with the KBS-3 method. The system comprises the existing interim storage facility CLAB, an encapsulation plant, a deep repository, a canister factory and a transportation system. The facilities are being designed to encapsulate and deposit approximately 200 canisters per year.

After interim storage in CLAB, the spent nuclear fuel assemblies are transferred to the encapsulation plant. There they are placed in copper canisters delivered from the canister factory. After welding-on of a copper lid and quality inspection, the finished canister with spent nuclear fuel is transported to the deep repository for deposition. When all fuel has been disposed of, the deep repository can be closed.

BWR
Boiling Water Reactor

PWR
Pressurized Water Reactor

The quantity of spent nuclear fuel to be disposed of is dependent on the operating life of the Swedish NPPs. With an operating life of 40 years, some 40,000 BWR assemblies and 5,000 PWR assemblies are used, with a combined uranium weight of approximately 9,300 tonnes. Around 4,500 canisters are needed to dispose of this fuel.

Functional requirements for the system have been formulated based on the requirements in laws and international agreements (Chapters 4 and 5). The design of the system as a whole is primarily governed by the requirements on the long-term safety of the deep repository.

The overall requirements for the encapsulation plant are to safely receive spent fuel from CLAB and encapsulate it in accordance with the specifications that have been formulated to meet the requirements in the deep repository. The requirement on the canister factory is that it must be able to fabricate canisters in accordance with the stipulated specifications.

The combined function of the facilities in the system is thereby specified on a general level. On a more detailed level, many judgements (optimization) are necessary to achieve a good and safe function of the entire system. Furthermore, site-specific data are needed for the detailed design of the facilities.

6.1.1 Interim storage facility for spent nuclear fuel

The radioactivity declines by about 90% when the fuel is stored for 30 years in CLAB

The interim storage facility for spent nuclear fuel consists of a receiving section above ground, an underground rock cavern with storage pools and a fuel elevator between them. All handling and storage in CLAB takes place under water, providing effective radiation shielding and cooling of the fuel. During approximately 30 years of interim storage, the radioactivity and heat output of the fuel decline by about 90 percent, simplifying subsequent handling.

An additional rock cavern is under construction and is scheduled to be completed in 2004. This will increase storage capacity from 5,000 to 8,000 tonnes of uranium.

6.1.2 Encapsulation plant

In the encapsulation plant, Figure 6-2, the spent nuclear fuel is placed in canisters with such properties that the fuel in the deep repository will be isolated from its surroundings and radionuclides will be prevented from escaping for a very long time.

The encapsulation process begins with transport of the fuel from the pools in the encapsulation plant via a transport ramp to a radiation-shielded handling cell for drying and placement in canisters. After the canister has been filled with fuel,

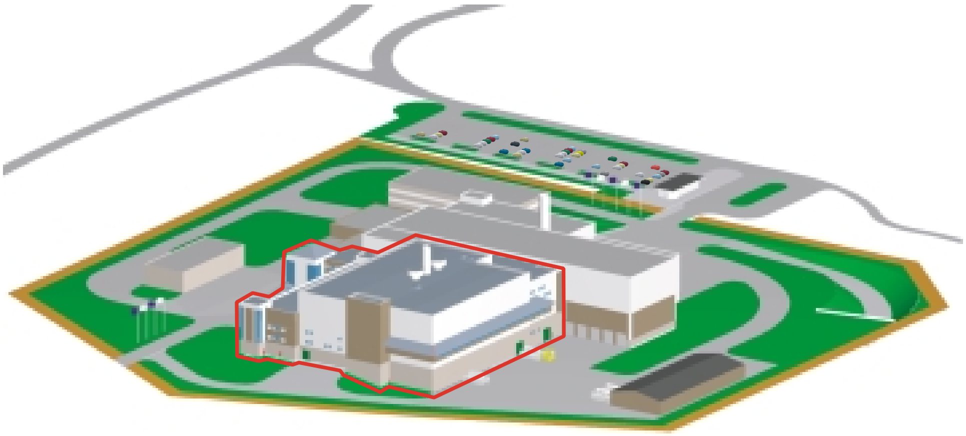


Figure 6-2. *Planned design of encapsulation plant (outlined in red) for a siting at CLAB.*

a copper lid is welded on. After inspection of the canister, to check e.g. the quality of the lid weld, it is placed in a transport cask, which is driven to the deep repository or to a store for filled transport casks.

The technology for handling of fuel assemblies and canisters, welding of canister lids and nondestructive testing of the lid weld by means of radiographic and ultrasonic methods is being developed and tested in SKB's Canister Laboratory in Oskarshamn. The development work will continue for another three to four years. An updating of all process data is planned during the latter part of this period.

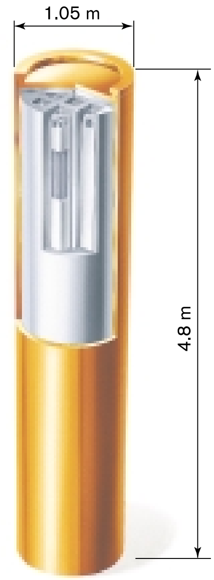


Figure 6-3. *Canister for spent nuclear fuel.*

In the reference design, the copper canister consists of a cast iron insert with steel lid surrounded by a 50 mm thick copper shell, see Figure 6-3. A complete canister with fuel weighs approximately 25 tonnes. The design premises for the copper canister are given in /6-3/.

Design of the encapsulation plant is being pursued in parallel with canister and process development. The plant comprises an encapsulation building and a store for filled transport casks.

The investment in the encapsulation plant is estimated at approximately SEK two billion. The operating costs, including the cost of canisters, is estimated to amount to around SEK five billion. Approximately 40 persons will staff the plant during the operating phase.

6.1.3 Canister factory

Extensive efforts are under way to formulate requirements and premises for the fabrication of copper canisters and cast iron inserts /6-4/. Three different methods are being tested for fabricating the copper canister: welding of roll-formed tube halves, extrusion, and pierce and draw processing. Lids and bottoms of copper are machined from forged blanks. Serial fabrication in the canister factory is planned to take the form of finish machining of pre-cast, -forged or -rolled blanks.

The methods for fabricating copper canisters and inserts are being developed in conjunction with the fabrication of trial canisters for the development work in SKB's Canister Laboratory and for the full-scale deposition trials in the Äspö HRL. Up to December 2000, SKB had fabricated some ten or so canisters.

The investment cost for the canister factory has been estimated at around SEK 300 million /6-4/. The final design and cost are dependent on available resources on the site. A workforce of around 30 persons is required to operate the plant.

Roll forming

Forming of plate into tube halves

Extrusion

Squeezing seamless tubes through a die

Pierce and draw processing

Forming seamless tubes by first piercing and then stepwise drawing over mandrels

6.1.4 Deep repository

The deep repository consists of an underground portion, approximately 500 metres below the ground surface, and a surface portion, which are connected to each other via ramp or shaft, see Figure 6-4. The underground portion consists of a central area, an area for deposition of fuel during an initial period (demonstration deposition) and a deposition area for regular operation. SKB's reference design entails that:

- The tunnels are blasted using conventional blasting technology.
- The canisters are deposited one by one in holes bored in the floors of the tunnels.
- The buffer consists of pure bentonite.
- Backfilling after concluded deposition in a tunnel is done with a mixture of bentonite and crushed rock.

The deposition tunnels are linked together by tunnels for transport, communication, ventilation and utility lines. The deposition holes are approximately eight metres deep and have a diameter of 1.75 metres. The canisters are embedded in a buffer of highly compacted bentonite.

The spacing between the deposition tunnels, as well as the spacing between the deposition holes, is determined by the need to limit the temperature on the canister surface. In the main alternative, the spacing between the tunnels is 40 metres and between the centres of the deposition holes at six metres.

The deep repository's surface facilities, see Figure 6-5, comprises a terminal building for receiving transport casks containing encapsulated fuel, a production building for preparation of buffer and backfill material, supply buildings for ventilation and electric power, plus personnel, garage, office, workshop and information buildings. If an inland location is chosen, the canisters of spent nuclear fuel will be transported by road or rail to the deep repository and taken down to the deposition area via a ramp.

The buildings can be located in one or two areas, depending on local conditions on the selected site. In the version with one area, an area of about 0.3 square kilometre is needed. A large portion of this area is occupied by a marshalling yard and by areas for heaps of rock spoils. The space requirement will be less if a railway is not needed and/or if the rock spoils heaps can take some other form.

The costs of building and operating the deep repository amount to a total of SEK 13 billion. The facility will be staffed by some 200 persons. The entire operating phase is projected to extend from around 2015 to 2050.

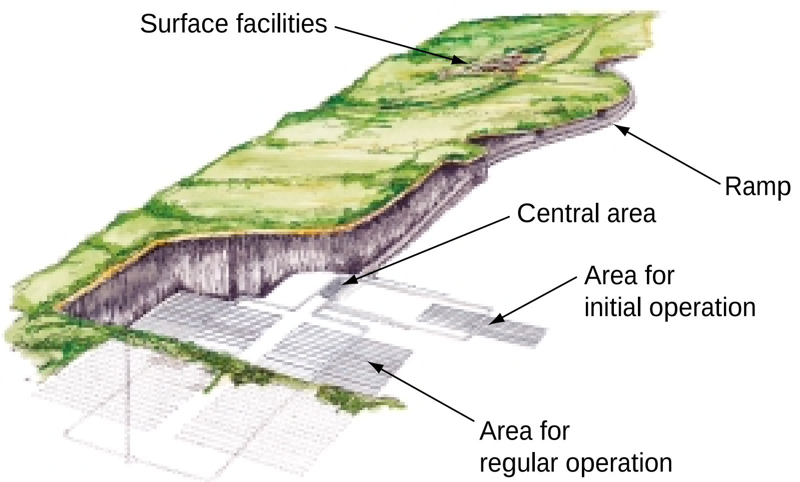


Figure 6-4. *Layout of the deep repository with a straight ramp from the surface portion to the underground portion.*

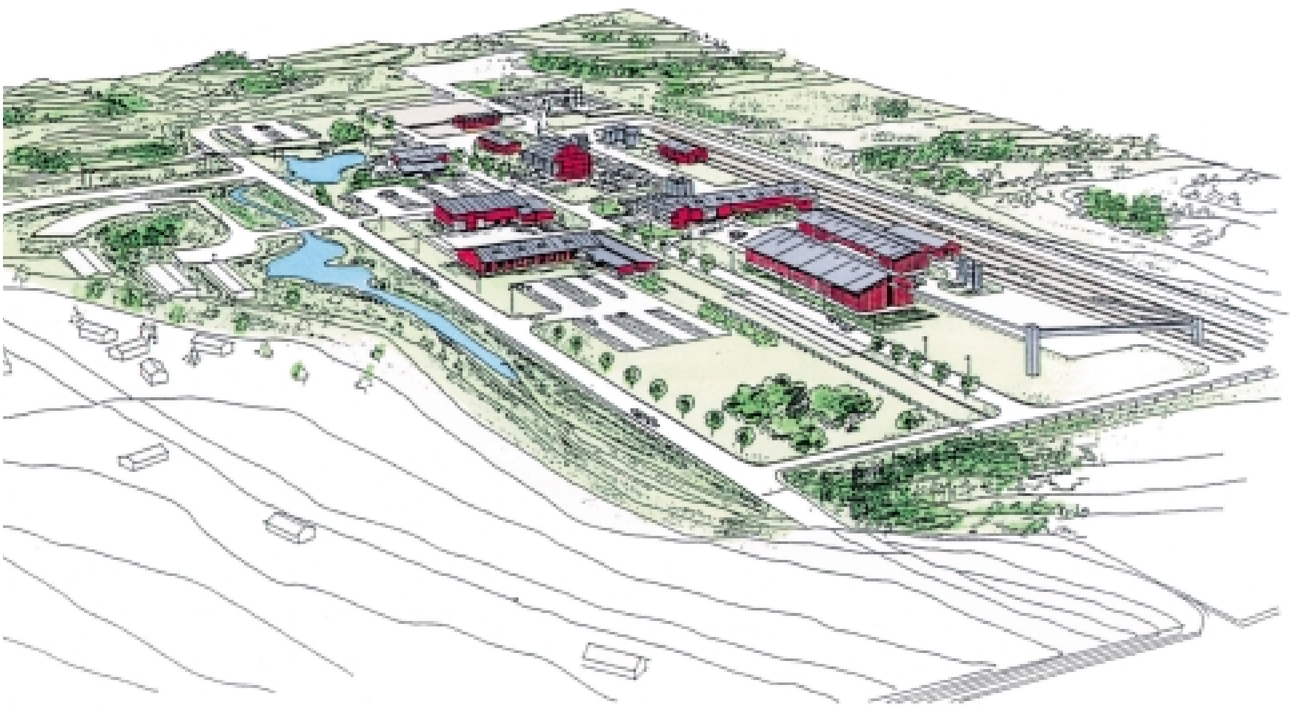


Figure 6-5. *Preliminary layout of the deep repository's surface facilities for an inland location and with rail transport.*

6.1.5 Transportation

The transportation system will be based on the good experience from more than 15 years of operation of today's transportation system, which consists of the ship M/S Sigyn, transport casks and containers, and terminal vehicles. The system will need to be augmented with transport casks for canisters, see Figure 6-6, similar to the ones used today for the fuel shipments to CLAB. The transport cask provides radiation protection, protects the canister against handling damage and prevents radioactivity from escaping in the event of possible accidents.

The shipments can go by sea, rail or road, or a combination of these transport modes, depending on the siting of the deep repository. The design of the transportation system for future transport of encapsulated fuel cannot be finalized until the siting of the encapsulation plant and the deep repository has been decided.

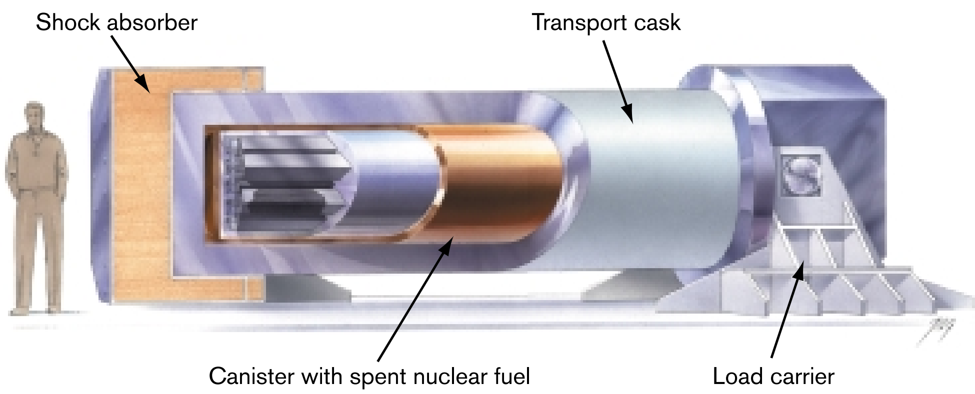


Figure 6-6. *Transport cask for canisters.*

6.2 Environmental impact

The erection of the industrial facilities included in the system will give rise to environmental impact. If the encapsulation plant and the canister factory are located on existing industrial sites, there will be little impact on the landscape and land use. If they are located on another site, there may be considerable environmental impact in these respects.

The land needed for the deep repository's surface facility is at most about 0.3 square kilometre. Altogether, it is estimated that 1–1.5 million cubic metres of rock will be blasted out during the construction and operating phases. By comparison, nearly 0.5 million cubic metres of rock were blasted out for SFR and approximately 200,000 cubic metres for CLAB (including the recently completed blasting of CLAB stage 2). This leads to a local drawdown of the groundwater table that can affect the supply of water in wells and the water content of nearby soils. The groundwater table is expected to be restored within a few decades after repository closure. Noise will be created by blasting and crushing of the rock spoils, heavy goods transport and the deep repository's ventilation system before closure. Water pumped up during construction and operation may require treatment before being discharged to sensitive watercourses.

Mining and processing of copper for fabrication of copper canisters is the greatest source of environmental impact. A total of approximately 35,000 tonnes of copper will be consumed for the 4,500 canisters. Annual copper consumption is equivalent to about 1.5 percent of Sweden's – and 0.01 percent of the world's – annual consumption. Approximately 15,000 tonnes of bentonite clay per year will be consumed during the operating phase. The bentonite can be imported from e.g. the Mediterranean area or the USA.

The transportation system can give rise to environmental impact in connection with construction of harbours, roads or railways and emissions from operation of the system. This is a factor that is taken into account in conjunction with the siting of the facilities in the system.

6.3 Safety and radiation protection

Safety for personnel and the public is achieved by designing the system to comply with the requirements on nuclear safety, radiation protection, safeguards and physical protection, as well as the requirements that apply to conventional industrial and rock facilities.

As regards nuclear safety and radiation protection during operation of the facilities, established principles and experience from existing facilities in Sweden and abroad can be applied, both from normal operation and from disturbances and accidents. Operating experience from CLAB since 1985 is good and shows that a high safety level can be maintained.

Spent fuel handling in the encapsulation plant and the deep repository exhibits many similarities to that in CLAB. Radiation doses to the personnel in CLAB have on average been less than one-third of the design-basis doses.

Fuel containing less radioactivity, and thereby with lower decay heat, than in CLAB is handled in the encapsulation plant and the deep repository. Neither disturbances (such as component faults and operator errors), possible accidents (such as fire), handling of spent fuel and canisters nor external forces (earthquake) cause damage to the fuel of any consequence to the environment. Releases of radionuclides from the encapsulation plant are estimated to be small, on the same level as for CLAB. LILW arises during operation in a similar manner as in CLAB.

The encapsulated spent fuel is handled in radiation-shielded transport casks in the deep repository. All handling of these casks takes place by remote control or

Figure 6-7. *The current version of the deposition machine in the demonstration facility in the Äspö HRL. The radiation protection tube in which the canister is transported up to the deposition hole can be seen in the middle.*

from behind radiation shields, see Figure 6-7. Due to this radiation-shielded handling, there is little increase in radiation doses to the personnel even in the event of accidents. No radioactivity can be released from the possible accidents that have been analyzed. Radon from the rock is dealt with in the same way as in connection with mining activities. This imposes special requirements on ventilation. The deep repository facilities do not otherwise give rise to radioactive releases to air or water.

Safety in conjunction with the transport of encapsulated fuel has also been studied. The canisters are transported in robust casks that can protect the contents against even rough treatment. Even in the event of serious accidents, for example ship collision combined with fire, the individual doses are well below harmful levels.

All factors considered, the system for handling and deposition of spent nuclear fuel is designed for the large quantities of radioactivity present in the fuel and for the radiation that is emitted. Doses to personnel will lie well below the design-basis and limit-setting levels. This applies to releases from the encapsulation plant as well.

Long-term post-closure safety has been the subject of extensive research. The SR 97 safety assessment and its review by an international expert group and by SKI are summarized in Chapter 7.

There are well-established procedures at the NPPs and at CLAB for control and monitoring of nuclear material (safeguards). The system includes documentation of all measures performed as well as frequent and sometimes unannounced inspections by Euratom and the IAEA. It is judged that more or less similar safeguards procedures can be used at the encapsulation plant as at CLAB. After encapsulation, verification and measurement of individual fuel assemblies is no longer possible. This imposes new requirements on the control functions.

Euratom
European Atomic Energy Community

IAEA
International Atomic Energy Agency

The physical protection includes the guarding and the technical and administrative measures taken to protect the fuel from theft or sabotage and to permit quick discovery and alarm if anything abnormal should occur. The system for surveillance and communication used in connection with today's transport and storage of spent fuel and radioactive waste is expected to be able to serve as a model for the new facilities as well.

6.4 Freedom of choice for execution

In the stepwise work of designing the deep repository, SKB strives to retain freedom of choice until sufficient knowledge has been accumulated as a basis for a well-founded choice between alternative approaches. This makes it possible to make use of technical advances and new building and manufacturing methods, as well as to build robust and effective safety systems within given frames for safety and radiation protection.

The ongoing work of defining the design premises for the deep repository, where permissible intervals for different parameters are to be stipulated, represents the first step towards a more precise specification of the system. The site investigations are another important step, leading to more accurate knowledge of the properties of the rock. This knowledge can be used in progressively improved safety assessments and for a narrower choice of parameters in the system.

6.4.1 Repository design

The depth of the repository is chosen with regard to the properties of the bedrock on the site. Tunnelling and boring of deposition holes can be done by means of various methods. In the main alternative, tunnels and ramp are excavated by means of conventional technology, drilling and blasting. An alternative, primarily for the deposition tunnels, is to use a tunnel boring machine that produces tunnels with a circular cross-section. The final choice will be made at a later stage depending on site-specific conditions.

In the main alternative, the deposition holes are bored vertically in the floor of the deposition tunnel. Figure 6-8 shows the main alternative and several other studied layouts for the deposition holes. Only Medium Long Holes (MLH) has been judged to be of interest from a safety and cost point of view for possible further study.

Backfill material in deposition tunnels and other tunnels can consist solely of crushed rock or quartz sand, or of a mixture of either of these with bentonite clay. Only natural materials with a high bentonite content may also be used.

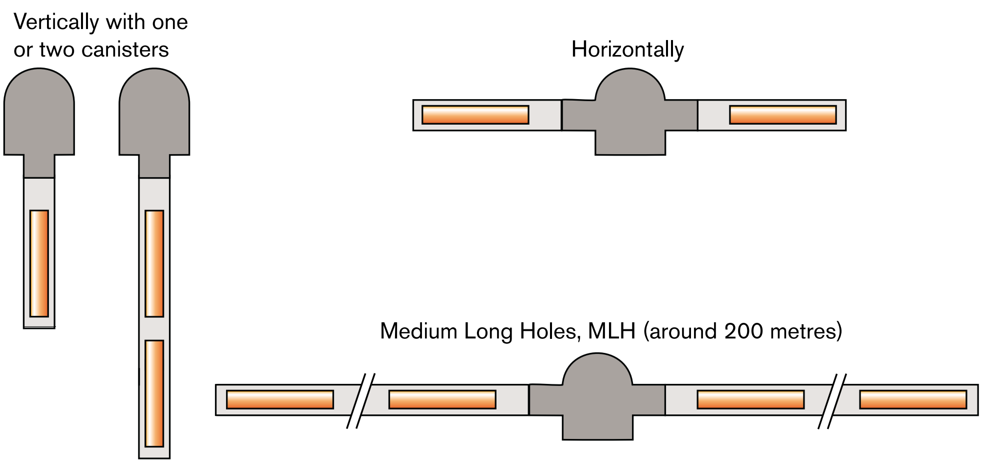


Figure 6-8. *Variants of disposal according to the KBS-3 method.*

The choice of technical solutions is in many cases dependent on local conditions on the site of the deep repository and on the properties of the bedrock. The descent leading down to the deep repository's underground facility can, for example, take the form of a spiral ramp, a straight ramp or a shaft. A spiral ramp is the most suitable descent to the underground facility if the surface facility is situated directly above the underground facility. In the main alternative, all heavy goods transport takes place on a ramp.

6.4.2 Barriers

An important part of the continued development work is to re-examine the requirements on the barriers and work out detailed specifications. Economic aspects are also taken into account here.

An important parameter that can be varied is the wall thickness of the copper canister. It is chosen primarily to comply with the requirement that the canister should be resistant to corrosion for a long time. In the reference alternative the wall thickness is 50 millimetres /6-3/. It is judged possible to reduce this thickness without compromising safety. A thinner copper wall facilitates welding of the lid and inspection of the weld. The copper must, however, be thick enough to provide sufficient strength during fabrication and handling. An alternative with a wall thickness of 30 mm is currently being studied.

The thickness and quality of the buffer are other parameters that need to be determined with regard to several factors. On the one hand, the buffer must be thick enough to protect the canister in the event of movements in the rock, to stabilize the canister and to retard the transport of the radionuclides. On the other hand, a thicker buffer leads to a higher temperature of the canister, which can be counteracted in different ways. The quality of the buffer can be modified to give it greater thermal conductivity. Alternatively, the spacing of the deposition positions can be increased to reduce the heat from nearby canisters. A thicker buffer and more widely spaced canisters require greater space and result in higher costs.

The properties of the engineered components in the system – canister, buffer, backfill and plugs – can be influenced by means of choice of materials, design and fabrication processes. This is not the case with the bedrock. For this reason, the approach used to satisfy the requirements on the bedrock is different than for other components. The principle is to select a site, based on progressively more detailed investigations, where the bedrock satisfies fundamental requirements and provides favourable conditions in other respects, and then adapt the layout of the repository to conditions on the site.

The repository is adapted to the bedrock on the selected site

6.4.3 Siting

Siting of the deep repository is dealt with in Parts III and IV.

According to the main alternative, the encapsulation plant is to be sited at CLAB. A co-siting with the deep repository is also possible /6-4/. Co-siting with some other existing nuclear installation or locating on a completely different site has not been explored. A comparative analysis considering such aspects as safety, technology, transportation and costs will be done before a decision is made on siting in conjunction with application for a permit to build the facility.

The canister factory should be located on a site with a suitable infrastructure and easy transport access.

6.5 Timetable

The timetable for building the encapsulation plant and the deep repository (see Chapter 2, Figure 2-3) is governed by the time needed for the site investigations, licensing and the societal communications required during the course of the siting process. The current schedule for the deep repository calls for the start of initial operation of the deep repository in 2015, involving deposition of 200 to 400 canisters, equivalent to 5–10 percent of the total quantity of spent fuel. The encapsulation plant is planned to be finished a year or so earlier.

Initial operation of the deep repository can commence in around 2015

Before a licence is granted for regular operation, experience from the initial operating period will be evaluated and reported. The evaluation prior to regular operation should start as early as possible and be carried out in parallel with initial operation. In this way the facilities and the personnel can be used in a rational manner. The remaining 4,000 or so canisters will be produced and deposited during regular operation, lasting about 30 years.

Initial operation will be evaluated before regular operation commences

6.6 Retrieval of deposited canisters

The long time horizon for repository function has led to the formulation of special ethical requirements. One requirement is that handling of the waste from today's energy production shall not impose undue burdens on future generations /6-5/. This means that the deep repository should be built without unnecessary delay, and that the post-closure safety of the repository should not require recurrent supervision and maintenance.

After closure, the repository shall be safe without requiring supervision or maintenance

Another requirement is that future generations should have the right to make decisions under their own responsibility on measures that could affect the repository, for example to retrieve the waste in order to utilize resources then judged to be valuable, or to modify the disposal scheme.

The repository, with durable barriers, is primarily designed to provide long-term safety. At the same time, its design allows good opportunities for retrieval during the operating phase. The stability of the rock and the canister also permit post-closure retrieval far in the future. Such retrieval is, however, not a simple matter. It is an operation of nearly the same scope as deposition in terms of time and money. Nevertheless, the KBS-3 system includes no measures in the handling of the fuel or in the construction of the repository that might unnecessarily hinder retrieval. Nor, on the other hand, have measures been taken to simplify retrieval that might compromise safety or radiation protection for the repository. If retrieval were to be carried out, it would require a safety assessment and permits like any other nuclear activity.

6.7 Conclusions

The analysis of the system for deep disposal according to the KBS-3 method shows that there are good prospects of satisfying all requirements stipulated on the system. The radiation doses to personnel and the surrounding environment are expected to be low in connection with normal operation, disturbances and accidents.

There are still considerable degrees of freedom before the design of the system needs to be finalized. This also applies to siting of the facilities and the timetable for carrying out the work. With the stepwise implementation planned by SKB, progressive and relatively late decisions can be made based on the new knowledge that emerges from SKB's RD&D programmes and from similar programmes in other countries.

7 Long-term safety

The next stage in the siting of a deep repository involves investigating the bedrock at a number of candidate sites. In preparation for this stage, SKB has carried out a new assessment of the long-term safety of the repository.

The assessment confirms the earlier picture that a KBS-3 repository in rock that does not differ significantly from normal Swedish bedrock has good prospects of meeting the requirements on long-term safety with good margin.

We judge that the repository design has achieved sufficient maturity and that our understanding of the long-term function of the repository is sufficiently good to carry out site investigations. The Swedish authorities and an international team of experts support this judgement.

An assessment of the long-term safety of a deep repository for spent nuclear fuel comprises a cornerstone in the total body of material gathered in preparation for the selection of sites for site investigations. This has also been expressly requested by the Government /7-1/.

The government and regulatory authorities also say that the assessment should be reviewed by both international experts and Swedish authorities, and that the results of this review should also be available prior to site selection. SKB also regards this as important, since many of the technical analyses and expert assessments in a safety report are difficult to comprehend for many of those involved in a site selection process, whereas the results of independent reviews of SKB's work should provide a more useful basis for decision.

SKB submitted the safety assessment /7-2/ requested by the Government in December 1999. The assessment is called SR 97 and the report has been reviewed by international bodies and Swedish authorities during 2000. The contents of SR 97 are summarized in this chapter in sections 7.1 and 7.2. The next two sections describe first the international and then the Swedish review of the report. SKB's comments on and conclusions regarding the review results conclude the chapter.

SR 97

Safety Report 97 SKB's most recent safety assessment

7.1 Premises for SR 97

7.1.1 Purposes and delimitations

The SR 97 safety assessment has four concrete purposes, based on what was requested by SKI /7-3, 4/:

1. SR 97 shall serve as a basis for demonstrating the feasibility of finding a site in Swedish bedrock where the KBS-3 method for deep disposal of spent nuclear fuel meets the requirements on long-term safety and radiation protection that are defined in SSI's and SKI's regulations.
2. SR 97 shall demonstrate methodology for safety assessment.
3. SR 97 shall serve as a basis for specifying the factors that serve as a basis for the selection of areas for site investigations and for deriving which parameters need to be determined and which other requirements ought to be made on a site investigation.
4. SR 97 shall serve as a basis for deriving preliminary functional requirements on the canister and the other barriers.

In addition, a number of fundamental premises and delimitations apply:

- SR 97 deals with a repository of the KBS-3 type for spent nuclear fuel. A preliminary facility design and safety assessment for a repository for long-lived LILW has been prepared in parallel with SR 97 and is presented in a separate report /7-5/. The repository can be co-sited with the repository for spent nuclear fuel or with the final repository for radioactive operational waste, SFR, which is in operation today. The repository can also be sited separately.
- In SR 97 it was assumed that 8,000 tonnes of spent nuclear fuel is deposited in the repository after 30 to 40 years of interim storage. 8,000 tonnes is equivalent to an operating life of between 25 and 40 years for all Swedish nuclear reactors. (SKB's most recent long-term plan assumes that 9,800 tonnes will be stored based on 40 years of reactor operation, see section 6.1. The difference does not affect the analysis and conclusions in SR 97.)
- To shed light on varying conditions in Swedish bedrock, data are taken from three different sites in Sweden.
- SR 97 has to do with the long-term post-closure safety of the repository. The repository's construction and operating phases are not dealt with. Safety during these phases, as well as other aspects that pertain to the whole disposal system (encapsulation, transportation and deep disposal) are summarized in Chapter 6 above. Nor is safety in connection with a prolonged open period or a partially closed repository explored in SR 97.
- The regulations from SSI state that human beings in the vicinity of the repository may not be exposed to an annual risk of more than one in a million of being harmed by radioactive releases. This is an important criterion that is used in SR 97 to assess the repository's safety. Coming regulations from SKI are expected to require an account of safety extending one million years into the future. This is also applied in SR 97.

7.1.2 Safety principles

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

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

7.1.3 Timescale

The repository should function as long as the waste is hazardous (see section 1.4). After approximately 100,000 years, the radiotoxicity of one tonne of spent fuel is roughly on a par with the toxicity of the eight tonnes of natural uranium used for fuel fabrication.

The figure of 100,000 years can therefore be used as a guideline for how long the repository has to "function". However, this figure should not be regarded as an absolute time limit in the evaluation of repository safety:

- On the one hand, the radiotoxicity of the fuel declines steadily and has e.g. after a thousand years fallen to approximately one-tenth of the level at deposition. This is important in the evaluation of the repository's safety. With time, uncertainty regarding conditions in and around the repository grows, but at the same time the radiotoxicity of the fuel diminishes.
- On the other hand, even after 100,000 years there are both small quantities of radionuclides that can move relatively easily through the repository's barriers if the copper canister should be damaged, and large quantities of low-mobility nuclides.

The safety of the repository thus needs to be evaluated far into the future and constantly in the light of how radiotoxicity declines with time. In SR 97, safety is discussed one million years ahead in time in accordance with expected regulations from SKI, see above.

The assessment covers one million years

7.1.4 Three sites

The deep repository will be situated in crystalline rock of granitic composition. Three hypothetical repository sites are analyzed in SR 97 to illustrate actual conditions in Swedish bedrock. Data were obtained from Äspö in Småland (southern Sweden), Finnsjön in Uppland (central Sweden) and Gideå in Ångermanland (northern Sweden), see Figure 7-1. The sites represent three areas in stable geological settings. All three sites are relatively near the coast, and Äspö is an offshore island.

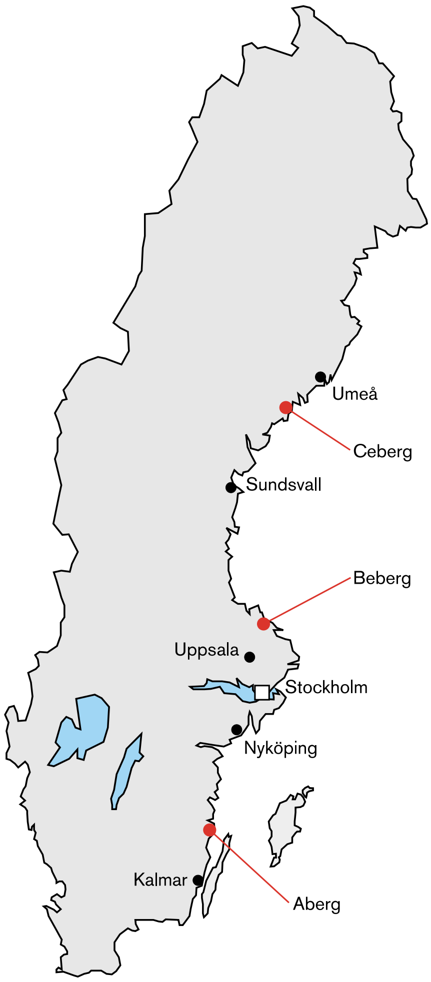


Figure 7-1. *Data for the hypothetical repository sites Aberg, Beberg and Ceberg are taken from Äspö, Finnsjön and Gideå, respectively.*

The three sites have been investigated on different occasions over a twenty-year period in studies of somewhat differing purpose and scope. The quantity of material is greatest for Äspö and smallest for Gideå. The repositories analyzed at the three sites are hypothetical. To underscore this, the names Aberg, Beberg and Ceberg will be used from now on for the sites with data from Äspö, Finnsjön and Gideå, respectively.

7.1.5 Methodology

Safety assessment is the method used to systematically analyze and assess the performance and safety of a deep repository. A safety assessment of a deep repository can be said to consist of the following tasks:

- carefully describe the appearance or state of the repository system at some starting point, for example when it has just been closed,
- describe what changes the repository could conceivably undergo in time as a consequence of both internal processes and external forces,
- evaluate the consequences of the changes for safety.

Biosphere
Part of the earth that contains life

One of the fundamental elements in the methodology is dividing the analysis into a number of scenarios. The evolution of the disposal system in the event of e.g. climate changes, earthquakes or initial canister damage is studied. A large part of the analyses within different scenarios consists of more or less complex model calculations. This applies above all to analyses of groundwater movements in the rock and of radionuclide migration in the different parts of the repository and in the biosphere. The consequences of individual and combined scenarios are weighed together in the final assessment of repository safety.

Just as important as the assessment of the repository's protective capacity is the question of how much confidence can be put in the results. The data underlying a safety assessment are always associated with deficiencies of various kinds. It is, for example, never possible to know in detail the fracture structure of the host rock or to be certain about the future climate. Repository safety must therefore be evaluated in the light of shortcomings of this kind. To put it simply, we are faced with the task of showing that the repository has been designed with sufficient margins to be safe in spite of the incomplete knowledge available. Confidence in the results is dependent on how methodically the uncertainties and deficiencies have been handled.

7.1.6 Choice of scenarios

Five scenarios are analyzed in SR 97. The choice is SKB's judgement of what initial and ambient conditions are important to shed light on in a safety assessment. The selection is based on, among other things, experience from previous work and information in databases on factors and conditions that are relevant for safety. Experience from previous safety assessment carried out by SKB and other organizations has also been drawn on.

The scenarios in SR 97 are:

- A base scenario where the repository is conceived to be built according to specification, where no canisters have fabrication defects and where present-day ambient conditions are assumed to exist.
- A canister defect scenario which differs from the base scenario in that a few canisters are assumed to have initial defects.
- A climate scenario that deals with future climate changes.
- An earthquake scenario.
- A scenario that deals with future human actions that could conceivably affect the deep repository.

The base scenario comprises a reference for comparison with other scenarios.

7.2 Results and conclusions in SR 97

This section begins with a brief presentation of the results of the analyses of the five scenarios. This is followed by a discussion of what the results say about the main purposes of SR 97, namely to a) investigate the feasibility of building a safe deep repository of the KBS-3 type in Swedish bedrock, and b) demonstrate a methodology for safety assessment. The section also shows how the analysis results serve as a basis for determining important factors in site selection, for formulating a site investigation programme and for formulating requirements on the canister and other barriers.

7.2.1 Base scenario

In the base scenario, the repository is conceived as being built entirely according to specifications and it is assumed that today's ambient conditions, for example the climate, persist. With these premises, the copper canisters are expected to retain their isolating function for millions of years on all analyzed sites and no releases will therefore occur from the repository.

The mechanical stresses on the canister from groundwater pressure, the pressure from the swelling buffer and the pressure from rock movements around the deposition holes are all far less than is required to jeopardize canister isolation. Nor can the chemical stresses on the canister in the form of corrosion cause damage to the copper shell that jeopardizes isolation, even on a million-year timescale.

This judgement is based on the assumption that the canister's surface temperature is lower than 100°C and that the water at repository depth is oxygen-free. The former condition can always be achieved by means of a suitable positioning of the deposition holes or by adjusting the fuel content of the canisters. Dissolved oxygen has never been observed in deep Swedish groundwaters. As a rule, oxygen in rainwater is effectively consumed in the soil layer. Moreover, there are microbes in the rock and in the minerals in both rock and buffer with a great potential for oxygen consumption. No long-term changes or processes have been identified in the base scenario that contradict the conclusion that the groundwater at repository depth will remain oxygen-free on a million-year timescale.

The judgement regarding canister integrity is also based on the assumption that the buffer functions as intended, which means that the buffer should have sufficiently low hydraulic conductivity, sufficiently high density and sufficient swelling pressure. Processes such as ion exchange, mineral alterations and erosion do not lead in the base scenario to any changes in the properties of the buffer that could jeopardize buffer function, even on a million-year timescale. The result is expected inasmuch as the buffer material is taken from a natural environment where conditions for millions of years have resembled those at repository depth in Swedish bedrock.

7.2.2 Canister defect scenario

The premises in the canister defect scenario are the same as in the base scenario, except that a few canisters are postulated to have small initial defects so that isolation is incomplete right from the time of deposition. Nor are any radionuclides expected to be released in this scenario for tens of thousands or hundreds of thousands of years after deposition.

The consequences have been calculated up to one million years after closure, and all sites meet SSI's acceptance criterion for a deep repository. The margin is greatest at Ceberg and smallest at Aberg. The differences can be partially attributed to differences in the permeability of the bedrock at the three sites.

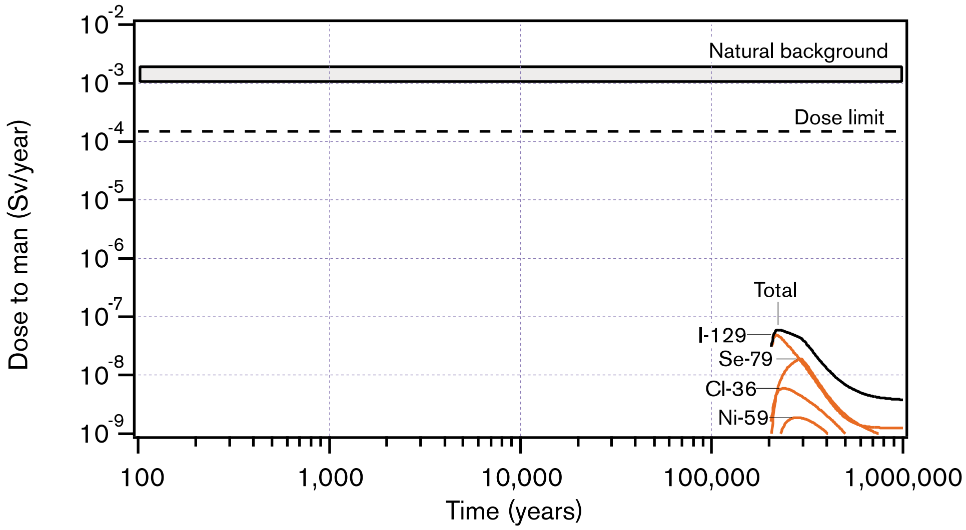


Figure 7-2. *An example of the results of the calculation of dose to humans at Aberg.*

Figure 7-2 shows a calculation result for Aberg. The figure shows dose to humans in the vicinity of the repository as a function of time. The release does not begin until 200,000 years after closure, since this is judged to be a reasonable value of the time it takes for water to penetrate all the way in to the fuel in a damaged canister. The judgement is based on analyses of the course of events inside an initially damaged canister.

The release to the biosphere is assumed to take place to a peat bog that is utilized for agriculture. This is the case that gives the greatest consequences in the model studies. Even though most releases at Aberg today would take place to the Baltic Sea, due to the ongoing process of postglacial land uplift (crustal upwarping), release to a peat bog is not improbable in the future. The dose from natural background radiation in Sweden (approx. 1 millisievert per year in this case) and the dose limit that can be derived from SSI's acceptance criterion for a deep repository (0.15 millisievert per year in this case) are also shown in the figure. The maximum release at Aberg is calculated to cause scarcely 0.0001 millisievert per year and occurs more than 200,000 years after closure.

The question of whether a water-filled canister could in any circumstances cause criticality, i.e. so that a self-sustaining chain of nuclear reactions is started, is also explored in the scenario. The analyses show, as do many previous similar calculations, that this is not the case.

7.2.3 Climate scenario

Permafrost

Ground that is permanently frozen

Expected long-term climate changes are also taken into account in the climate scenario, see Figure 7-3. In relation to the base scenario, a transition to a colder climate with permafrost and ice growth leads to the following:

- the conditions in the biosphere are altered radically,
- the temperature in the rock is affected,
- the conditions for groundwater flow are altered – the groundwater flow can both decrease and increase during different periods,
- the mechanical pressure in the rock changes in conjunction with a glaciation,
- the groundwater composition changes – the salinity of the water in particular will vary.

The most noticeable changes take place in the biosphere, for example when dry land becomes seabed and vice versa, or when a continental ice sheet covers an

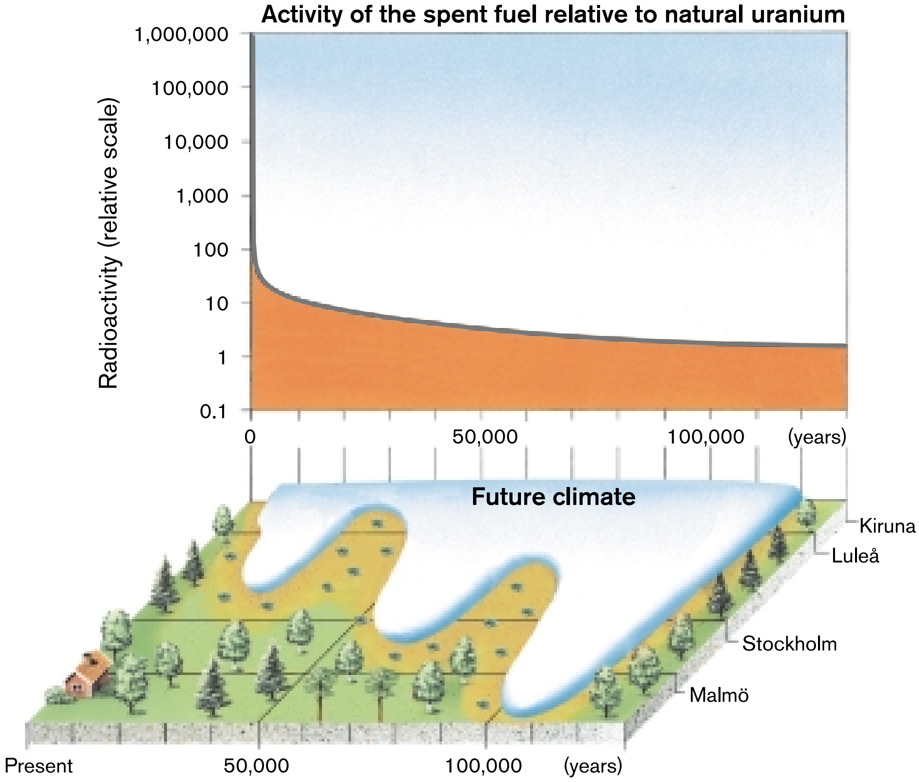


Figure 7-3. *Top part: The radioactivity of the spent fuel as a function of time. A value of 1 is the radioactivity in the quantity of uranium that is needed to produce the fuel. Lower part: Schematic illustration of ice sheet advance and vegetation up to the next ice-free period.*

area. The repercussions on the repository are not expected to lead to canister damage, not even with the most extreme glaciations that can be foreseen.

Initially damaged canisters generally have milder consequences in the form of dose to man in this scenario than in the canister defect scenario. This is primarily because the biosphere is altered powerfully with the climate. During long periods of time, the sites are expected to be covered by ice sheets or seawater and thus be uninhabited.

7.2.4 Earthquake scenario

The earthquake scenario examines how earthquakes can affect repository safety. The analysis is centred on the question of whether earthquakes can lead to a breach in isolation in one or more canisters.

The Swedish bedrock is of ancient origin and has low seismic activity in relation to many areas in the world. Quakes in Sweden mainly occur in the southwest in the Lake Vänern area and along the Norrland coast. The magnitude of the earthquakes has rarely exceeded 4. Earthquakes that occur in conjunction with one of the earth's tectonically active areas, e.g. Japan, the Caucasus or California, can have a magnitude of around 8, which means that nearly 1 million times more energy is released than by an earthquake of magnitude 4.

Magnitude
Strength of earthquake as measured on the Richter Scale

During the retreat of the ice sheet following the most recent ice age, earthquakes occurred with considerably greater magnitudes than what we know from historic time. Earthquakes with a magnitude of around 8 occurred then in northern Sweden. Similar quakes may also have occurred in other parts of Sweden during this time. The cause of these quakes has not been determined, but since they occurred during a limited period of time as the continental ice sheet was retreating, they are believed to have been related in one way or another to the rapid load changes that occurred during the process of deglaciation.

In order to study the effects of earthquakes, model simulations have been performed with data taken from the three sites. The method is the result of the first stage in the development of a procedure for quantitative analysis of earthquakes.

Even today's simulations, which contain many pessimistic assumptions, show that the probability of canister damage during a period of 100,000 years is of the same order of magnitude as that assumed for initial canister defects, i.e. fractions of a percent.

The pessimistic assumptions that are made in the risk assessment are judged to compensate with ample margin for other uncertainties, such as those that have to do with the predictions of future earthquakes. Just by making more realistic assumptions concerning e.g. the mechanical properties of the fractures, so much smaller rock movements are obtained that no canister damages are expected, provided the repository is situated at a greater distance than 100 metres from fracture zones with an extent of more than 100 kilometres. Such zones can easily be avoided when positioning a future repository, which means that the risk of canister damages caused by earthquakes can be considered to be negligible.

Consequently, earthquakes are not expected to lead to any canister damages. For this reason, no calculations of radionuclide transport are performed in the earthquake scenario in SR 97. The methodology for earthquake analyses will be further refined for future safety assessments.

7.2.5 Intrusion scenario

The possibilities of calculating the risks that human beings will disturb the repository in the future are greatly limited. Nor is it clear how such risks should be taken into account in the total assessment of public acceptance for a deep repository. SR 97 discusses how possible evolutions of society and future human actions impacting the repository can be categorized and expressed as different scenarios.

In an illustrative example, a situation is analyzed where a canister in the repository is accidentally penetrated by drilling. Dose and risk are calculated for the drilling personnel and for a family that settles on the site at a later time. If the drilling is carried out within approximately 300 years after the repository has been closed, the dose to the drilling personnel can exceed the background radiation and reach the levels that are permitted today for persons in radiological occupations. The probability of drilling through a canister is, however, very low even if the repository should be forgotten. The dose to the family is lower than to the drilling personnel and never exceeds the natural background radiation.

7.2.6 Safety of the KBS-3 method in Swedish bedrock

The results of the analyses in SR 97 show that the feasibility of building a safe deep repository of the KBS-3 type for spent nuclear fuel in Swedish bedrock is good. Fictitious repositories with real bedrock data from three different sites have been analyzed to shed light on variations in the conditions in Swedish crystalline bedrock.

The results of SR 97 thereby confirm the previous picture that a well-designed KBS-3 repository for spent nuclear fuel placed in rock with properties that do not differ significantly from normal Swedish rock has good prospects of meeting the authorities' safety requirements with good margin.

The KBS-3 system has a flexibility with regard to repository depth and layout that permits adaptation to site-specific conditions and to the information on rock conditions that is continuously collected during site investigations and repository construction.

SKB judges that the repository design that is analyzed in SR 97 has achieved sufficient maturity, that our general understanding of the long-term function of the repository is sufficiently good, and that the potential for high safety has sufficient margins to comprise a satisfactory basis for conducting site investigations.

7.2.7 Methodology for safety assessment

A safety assessment is both comprehensive and complex and requires a methodical approach to achieve reliable results. This applies not least to the handling of the different types of qualitative and quantitative deficiencies that will always be associated with the data for a safety assessment. This is a consequence of the fact that the assessment concerns conditions in a heterogeneous bedrock that can be observed directly only to a very limited extent and the fact that the assessment spans time periods that cannot possibly be studied in laboratory experiments. Many phenomena must therefore be described by means of simplified and pessimistic assumptions.

Several new methods have been tried in SR 97, among other reasons for a systematic account of available knowledge of different processes and for handling uncertainties. The methodology has proved to work well and is considered to comprise a good basis for further refinement for future assessments.

7.2.8 SR 97 as a basis for site investigations, system design and research programmes

SR 97 has comprised an important basis for formulating and quantifying requirements and preferences made by the deep repository on the rock based on the perspective of long-term safety. Experience from SR 97 has also been used in the work of formulating an integrated programme for investigation and evaluation of sites, see further Chapters 13 and 14. Finally, the results of SR 97 have been used to revise the design of the repository's barriers.

Experience from SR 97 comprises a basis for setting priorities in the programmes for supportive research, development and technology demonstration. The results indicate several areas that may need to be prioritized, such as:

- Biosphere modelling.
- Earthquake modelling.
- Backfill performance.
- Models for hydrology and radionuclide transport on a detailed scale around deposition holes to permit an optimal selection of deposition holes.
- Fuel dissolution.

New findings would often permit the use of less pessimistic premises in the safety assessment.

7.2.9 Summary

The next stage in the siting of a deep repository involves investigating the bedrock at a number of candidate sites. The main purpose of SR 97 in preparation for that stage is to "demonstrate that the KBS-3 method has good prospects of meeting the safety and radiation protection requirements which SKI and SSI have stipulated in recent years" /7-3, 4/.

The radiation levels which Swedish authorities accept for individuals in the vicinity of a deep repository lie at around one percent of the natural background radiation. The results of the analyses in SR 97 show maximum levels that are less than one-tenth of the authorities' requirements. The maximum levels will occur tens of thousands of years in the future and during the relatively short time intervals when candidate repository sites in Sweden are not expected to be covered by ice sheets or sea.

The results shall also be seen in the light of the cautious attitude that permeates the execution of the safety assessment. If available knowledge within any area is not complete, a poorer outcome than can be reasonably expected is pessimistically assumed.

SR 97 shows that the prospects for building a safe deep repository for spent nuclear fuel in Swedish crystalline bedrock are good. The assessment is comprehensive and detailed in an international perspective against the background of the next stage SKB is facing.

It is SKB's judgement that the scope of the safety assessment and confidence in its results amply satisfy the requirements that should be made in preparation for the site investigation phase.

7.3 International expert review

In order to obtain a broad international scrutiny of SR 97, SKI commissioned the OECD's Nuclear Energy Agency, NEA, to carry out a peer review. The NEA's secretariat has many years' experience of such assignments and gathers a team of experts from all over the world for each such peer review. The members of the team are appointed with reference to the contents of the safety assessment and the purpose of the review. Regarding NEA's choice of experts, SKI stipulated that no one who had worked under contract to SKB in the past six years could be used in the review.

The team's task was determined by SKI, and a primary task was to assess the methodology in SR 97. The results of the review serve as a basis for the Swedish regulatory review.

The IRT (International Review Team) assembled for the first time in Stockholm in December 1999 when SKB presented SR 97, which had just been completed. The reviewers studied the material for a couple of months and posed a number of questions to SKB. The questions were answered in writing, and in March 2000 the team once again assembled in Stockholm for four days of interrogation of SKB's experts. After further review a review report was compiled /7-6/ and published in Stockholm in May 2000.

7.3.1 Conclusions of the IRT

The IRT expressed great respect for the openness with which the Swedish process of developing and siting a deep repository is being conducted. In an international perspective, they observed a great willingness on the part of the Government, regulatory authorities, concerned municipalities and industry to engage in constructive and open discussions.

The conclusions chapter of the final report /7-7/ is reproduced below:

> "The KBS-3 disposal concept has the essential elements of a sound concept for the disposal of spent nuclear fuel in a geologic repository. It provides defence-in-depth through a set of passive barriers with multiple safety functions. The concept is based on well-established science and a firm technological foundation, is well defined, and appears to be implementable.
>
> SR 97 provides a sensible illustration of the potential safety of the KBS-3 concept that takes account of the conditions in Swedish bedrock, based on data from three sites. The documentation is generally well written and the arguments are well presented, but there is room for improvements in the completeness of arguments, traceability and transparency.

Given the current state of expertise of the SKB geoscience and engineering programmes and the favourable indications from SR 97, SKB's desire to move to a site-selection phase is well founded. This is reinforced by the observations that the performance of the geosphere barrier is site-specific and data are needed from potential sites to better develop, focus and test the SKB assessment methodology.

The review has not identified urgent issues that must be resolved prior to proceeding to the investigation of potential sites. Several observations and recommendations are made that SKB and the safety authorities may wish to consider in the future development of the Swedish safety assessment programme for spent fuel disposal:

- A high-level, periodically updated document describing SKB's safety strategy should be prepared. This would reveal the evolution of the KBS-3 concept and show how various technical studies have contributed to its development and to the understanding of the requirements for safety.
- More frequent, iterative safety assessments would facilitate the timely evaluation of the significance of new scientific and engineering information and enhance the role of safety assessment as a means to integrate the programme. More frequent assessments would also develop and ensure the continuity of staff experience and skills required to conduct such assessments.
- A number of technical issues have been identified, the resolution of which would enhance the robustness and transparency of the descriptions and arguments that support the safety case. More important examples relate to:
  - Documentation of the evidence and arguments leading to confidence in the maintenance of reducing groundwater conditions at repository depth.
  - Improved understanding of the origin and evolution of groundwater solutes.
  - Interpretation of the "flow-wetted surface" parameter, including methods to provide field data necessary to support its use, and
  - Definition of the expectations and requirements of biosphere modelling consistent with Swedish regulatory guidance and scientific constraints.
- Better definition of SKB's strategy for scenario selection could clarify the representativeness and purpose of the different scenarios, and how they build to an integrated evaluation of safety. In future assessments, more formal scenario development or selection techniques would be preferable.
- It would be beneficial to develop an integrated, and more comprehensive, approach to uncertainty and sensitivity analysis that covers a fuller range of parameter and model uncertainties and evaluates multiparameter sensitivities. Improved transparency is needed in the selection of parameter values defined as "realistic" or "pessimistic" in SKB's current method. Methods that permit the construction of probability distributions from limited amounts of data should be reconsidered.
- Discussion is required between SKB, SKI and SSI on the interpretation of the Swedish regulatory requirements related to risk and probability, the authorities' expectations, and practical methods that might be employed to calculate desired endpoints while preserving statistical veracity. Discussion is also required with SSI regarding their expectations for assessing impacts to the natural environment and how requirements might be met.

- In future safety assessments, consideration should be given to incorporating more realistic, as opposed to conservative, descriptions of the performance of the facility. The adaptation and completeness of the present scenarios to the conditions of specific sites should also be considered.

Incorporation of more comprehensive sensitivity and uncertainty analyses into the assessment methodology could help to guide site investigations, and specifically to identify which site-specific data are most important to safety and potentially to be obtained during the site characterization programme."

7.4 Swedish regulatory review

SKI and SSI conducted a comprehensive review of SR 97 during 2000, similar to the review of SKB's research programme conducted every third year. The reviewing authorities gave a large number of university departments, organizations and feasibility study municipalities, as well as KASAM (Swedish National Council for Nuclear Waste), an opportunity to air their views regarding the contents of SR 97. The results of the international peer review comprised an important basis for the work of the Swedish authorities.

7.4.1 Conclusions of Swedish regulatory review

SKI and SSI presented their review of SR 97 in mid-November in the form of a main report /7-8/ and a summary report /7-9/. Following is a translation of the conclusions in the summary.

"The Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Institute (SSI) have reviewed SR 97 in relation to its purposes, which are to demonstrate methodology for safety assessment, show that Swedish bedrock can allow safe final disposal using SKB's method, and serve as a basis for specifying which factors are of importance in the selection of a site and for deriving preliminary functional requirements on the technical barriers. The authorities have arrived at the following conclusions:

- No circumstances have emerged in SR 97 to indicate that geological disposal in accordance with SKB's method should have any crucial deficiencies in relation to the requirements made by the authorities on safety and radiation protection.
- SR 97 contains the constituents required to provide a comprehensive picture of safety and radiation protection.
- SKB's methodology for safety assessment has been improved in several important areas, for example as regards documentation of processes and properties that can affect repository performance, and development of calculation models for the safety assessment.
- The methodology in SR 97 has some deficiencies, for example when it comes to specifying which future events the safety assessment shall describe. SR 97 has not dealt enough with unfavourable conditions that can affect the future safety of a final repository.
- SKB says that the results of SR 97 have been used in the work of formulating requirements and preferences regarding the rock at a final repository. In the opinion of the authorities, it is not clear from SR 97 how this has been done. The coupling between site assessment and site investigations should be improved.

- A safety assessment of a final repository for spent nuclear fuel will always be burdened with uncertainties and deficiencies in the knowledge base. It is then up to experts to make the best possible judgements. SKB should develop better procedures for expert judgements.

In summary, the authorities conclude that parts of the methodology in SR 97 need to be further refined and defined in preparation for upcoming stages in the site selection process. SKB's development of methods for safety assessment is an ongoing effort that should continue throughout all stages of the construction of a repository.

After the review of SR 97 and the previous review of SKB's RD&D Programme, the authorities find that the KBS-3 method is a good foundation for SKB's future site investigations and the continued development of the engineered barriers.

The authorities intend to return with additional viewpoints regarding what reporting is needed at the different junctures in SKB's final disposal programme in conjunction with future reviews of SKB's RD&D programmes."

The summary report also states: "But a detailed body of data from site investigations and more extensive practical experience from fabrication and testing of the engineered barriers are required before a more exhaustive assessment can be made of the KBS-3 method. It is moreover necessary that SKB augment and refine its methods for safety assessment, taking into account the authorities' review of SR 97."

7.5 SKB's comments on the review results

It is urgent for SKB that the safety assessment be subjected to both national and international reviews. A safety assessment of the scope of SR 97 has not been done since the KBS-3 report was presented in 1984. Since then both methodology and the body of scientific data have developed considerably and it is important that SKB's assessment be reviewed by the world's leading experts in this field.

The International Review Team draws the important conclusion that SKB has well-founded reasons for moving on to the site selection phase. This is also SKB's judgement in the closing words of the SR 97 report, and it is valuable that this judgement is supported by the IRT.

The team's conclusions and recommendations are also valuable for improving the design of future assessments, as a basis for setting priorities in future research programmes, etc. The development work will be described in SKB's programme for research, development and demonstration.

After the review, the Swedish authorities draw the conclusion that the KBS-3 method is a good basis for SKB's upcoming site investigations and that nothing has emerged from SR 97 to indicate that the method should have any deficiencies in relation to the requirements made by the authorities. These are important conclusions in support of SKB's desire to proceed with site investigations.

The Swedish authorities also make numerous comments and offer many suggestions for further development that will serve as a basis for SKB's future research programmes. However, the authorities refrain from making formal demands on SKB in these matters until they have reviewed all material prior to site selection.

In one of the points quoted above, the authorities note quite correctly that SR 97 does not show how the results of the assessment are used to formulate requirements and preferences regarding the rock at a final repository. This was done in special reports during the spring of 2000 /7-10, 11/, see also sections

10.1 and 13.3. These reports are now being reviewed by the authorities, along with all other reports submitted by SKB in preparation for the site investigation phase. The review results will serve as part of the supporting documentation for SKB's next research programme, RD&D-Programme 2001.

In summary, SKB concludes that no obstacles to proceeding with site investigations have emerged in the reviews of SR 97. On the contrary, both the International Review Team and the Swedish regulatory authorities consider data from site investigations to be of urgent importance for being able to evaluate the KBS-3 method in greater detail.

Part III - Site

8 Siting process

Within a ten-year period, SKB plans to complete the siting of the encapsulation plant and the deep repository. The main question is where the deep repository is to be located. For the encapsulation plant, siting at CLAB is the main alternative, but the plant may be located at the deep repository or possibly in connection with an existing nuclear installation.

The siting work for the deep repository has now been going on for nearly ten years, with general siting studies of the entire country and feasibility studies of a total of eight municipalities. The result is a number of siting alternatives for which SKB judges the prospects to be good of both satisfying the requirements on safety and environmental protection and being able to implement the deep repository project in practice. SKB thereby considers there to be a solid basis for proceeding to the next phase of the process – the site investigation phase – where the studies will be concentrated on the most promising siting alternatives and boreholes will be drilled to investigate the bedrock on selected sites.

8.1 Progress so far

SKB's siting work is aimed at two nuclear installations: an encapsulation plant and a deep repository. A final repository for long-lived LILW will be added in a later phase of the nuclear waste programme (see Chapter 2).

A step-by-step siting process has been in progress for the deep repository since 1992. The goal is that siting should be completed within a ten-year period. Which locality and site is finally selected for the deep repository will determine much of the rest of the waste management system, see Figure 8-1. It affects the transportation system, the siting of the encapsulation plant and the canister factory, and in the long term where the focus of SKB's total activities will lie. For encapsulation, the main alternative is to build a plant next to CLAB, but the possibility of locating the encapsulation plant at the deep repository will also be explored.

The plans for encapsulation and deep disposal of spent fuel were presented by SKB in RD&D-Programme 92 /8-1/. The siting work was also commenced at that time. In August 1994, SKB published, at the Government's request, a supplement to RD&D-Programme 92 /8-2/. In that report, SKB described premises for the siting work and the planned scope and methodology for its execution. With the support of its own geoscientific investigations (the study site programme etc.), general knowledge of conditions in Swedish crystalline basement and results from various safety assessments, SKB drew the following fundamental conclusions:

- There are good prospects of finding sites in Swedish crystalline basement with conditions that are suitable for a deep repository.
- Suitable bedrock is not limited to any particular part of the country or geological province within the crystalline basement. The most important factor is instead local conditions.

The siting process

Gather general knowledge of bedrock characteristics (1976-

Establish premises and process (1992-1995)

↓

Conduct general siting studies and feasibility studies (1993-2000)

↓

Evaluate alternatives

Select sites for site investigations (2000-2001)

↓

Conduct site investigations (2002-2006)

↓

Propose site for deep repository

Submit application for licensing procedure (2006-2008)

This, concluded SKB, mean that it's possible to start with approaching municipalities that wished to participate in the siting process, which was regarded as a prerequisite for success in siting. The conclusions were formulated as followed in the summary of the supplement:

> "---the organization of the siting work is based on a conviction that it is necessary and possible to find a site that meets high environmental and safety standards at the same time as a local understanding for the establishment of a deep repository is sought. This approach is well in agreement with the intentions underlying the applicable legislation---"

This fundamental standpoint has served as a guiding principle in the siting work, and is just as applicable today as when the supplementary report was presented.

In the same report, SKB presented, more clearly than before, the technical and other requirements that should serve as a basis for the siting, as well as the factors that must be taken into account during the course of the work. Clear definitions were given of the concepts general siting studies, feasibility studies and site investigations.

Today there is a defined process for the siting of the deep repository. It is the result of the siting studies which SKB has initiated and conducted, in combination with SKB's practice (established in 1986) of publishing regular accounts (the RD&D programmes), followed by regulatory review and Government decisions.

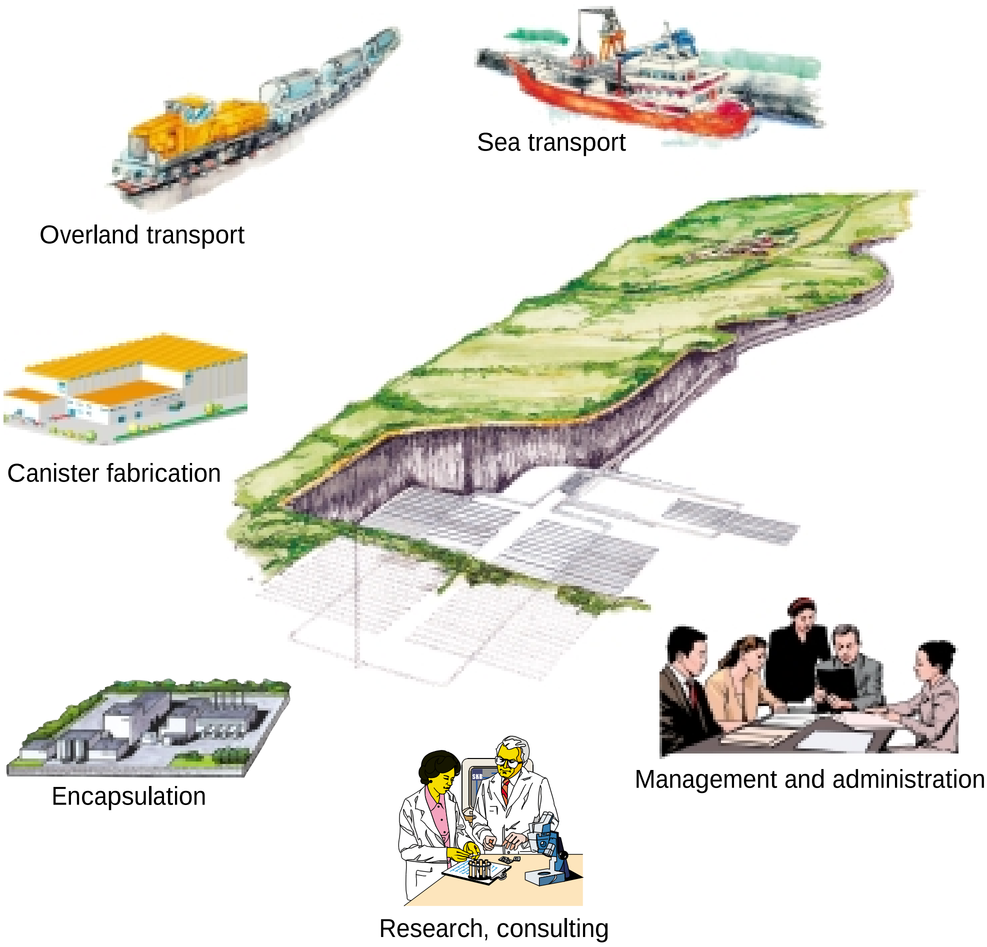


Figure 8-1. *The deep repository and other activities that are affected by where the deep repository is located.*

The process took shape primarily during the period from 1992 to 1995, and entails a division of the work of compiling siting data into two main phases: the feasibility study phase and the site investigation phase (see Figure 8-2).

The process has now come to the conclusion of the feasibility study phase, which for SKB has entailed:

- establishing the actual process,
- carrying out general siting studies and feasibility studies,
- gaining the support for and confidence in the nuclear waste programme, nationally and locally, that is a prerequisite for execution of the deep repository project.

The general siting studies have dealt with general siting prospects as regards important factors and different parts of the country. The feasibility studies, eight all told, have been performed to evaluate the siting prospects in:

- two municipalities in northern Sweden, Storuman and Malå, during the period 1993–1997. Local referendums in these municipalities led to their being omitted from further studies.
- six municipalities – Östhammar, Nyköping, Oskarshamn, Tierp, Älvkarleby and Hultsfred – during the period 1995–2001.

Even before the siting work for the deep repository was commenced in 1992, an extensive programme including test drilling on some ten or so sites had been carried out to build up the necessary knowledge of the intended setting for the deep repository, i.e. the Swedish crystalline bedrock. In addition, CLAB, SFR and Äspö HRL had been sited.

The collected experience possessed by SKB today as regards investigations and siting of facilities thereby comprises:

- Exploratory drilling and other investigations of the bedrock on ten or so sites in the country (known as the study site programme), 1977–85.
- Siting of CLAB on the Simpevarp Peninsula, 1976–79.
- Siting of SFR in Forsmark, 1980–83.
- Siting of the Äspö HRL, 1986–90.
- General siting studies and feasibility studies for the deep repository.

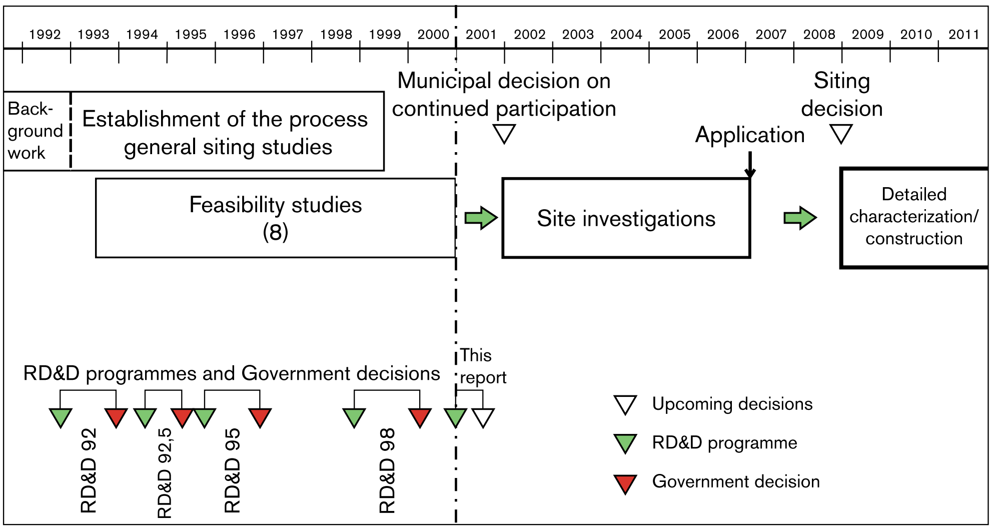


Figure 8-2. *Main elements of the siting process.*

This experience includes both successes and failures. The sitings of CLAB and SFR around twenty years ago were relatively simple to execute. The processes took several years and primarily involved SKB, the safety authorities and the concerned municipalities. The siting work for the deep repository has so far been accompanied by a both broader and deeper involvement in society. To some extent, this difference may be attributable to the fact that the deep repository project incorporates unique aspects, but it also reflects a trend in society, as a result of which siting projects have become much more complex and time- and resource-consuming to carry out.

SKB's view is that the extensive research, development and siting work that has been done has provided the data needed to move on to the next phase of the process: the site investigation phase. We also believe that the necessary interest in the nuclear waste issue and support for SKB's programme exists in society to make this continuation both possible and warranted.

The purpose of the site investigation phase is to complete the siting of both the deep repository and the encapsulation plant. The key issue is the siting of the deep repository, and the crucial tasks for SKB will be to:

Long-term safety

- Show that a deep repository on the selected site satisfies all requirements on safe long-term disposal. This requires safety assessments, which in turn require extensive investigations of the bedrock.

Technology, health, environment

- Show that a deep repository on the selected site satisfies all technical requirements, as well as health and environmental protection requirements. This requires a number of studies concerning transport prospects, land questions and environmental impact.

Societal aspects

- Obtain support for a siting of the deep repository from the municipality in question and from regulatory authorities and the Government.

8.2 Premises for the continued work

8.2.1 Division of responsibilities and requirements on SKB

Producer responsibility (see Chapter 3) entails in practice that SKB is responsible for compiling supporting material and applications for siting of the deep repository and the encapsulation plant. The regulatory authorities, the concerned municipalities and the Government decide whether or not to approve the applications. The responsibility of the authorities as reviewing bodies, as well as the responsibility of the Government for ultimate decision-making and the mandate of the municipalities, are clearly spelled out in the legislation. There is, in other words, an established division of responsibilities, which is a prerequisite for successful siting.

Government decision

- 5- 10 feasibility studies
- at least two site investigations
- integrated presentation
- programme for site investigations

Examination of siting applications will take place pursuant to the Environmental Code and the Nuclear Activities Act (see Chapters 3 and 13). These laws with associated regulations lay down the fundamental requirements that are imposed in connection with siting and building of nuclear installations. Moreover, in its decisions on SKB's RD&D programmes, the Government has stipulated conditions and provided directions that have guided the siting work. An important milestone in SKB's view is the decision that followed upon the supplement to RD&D-Programme 92 /8-3/ which states, among other things, that:

- The factors and criteria which SKB stipulated (in the aforementioned supplement) as providing guidance for siting "---should, in the Government's opinion, be a point of departure for the continued siting work".
- Applications for permits to build a deep repository "---should contain material for comparative assessments that shows that site-specific feasibility studies in accordance with SKB's account have been conducted at between 5–10 sites in the country and that site investigations have been conducted at at least two sites, plus the reasons for the choice of these sites".

The same Government decision laid down guidelines for licensing, emphasized the importance of consultation on the environmental impact assessment (EIA), clarified the county administrative boards' coordinating responsibility for contacts between SKB, authorities and municipalities, and strengthened the position of the participating municipalities.

In a later decision, occasioned by RD&D-Programme 95 /8-4, 5/ and RD&D Programme 98 /8-6, 7/, the Government states that:

- Before the site selection process can proceed to site investigations, concerned municipalities should have access to SKB's collective account of general siting studies, feasibility studies and whatever other background material and comparison material SKB may wish to present.
- Before the selection of sites for site investigations, SKB shall submit a "collective account of completed feasibility studies etc. and a clear programme for site investigations ---" to clarify that SKB's choices are founded on a solid basis.

Taken together, the laws and the Government decisions lay down clear requirements on the body of siting data which SKB is obligated to compile. As regards the time aspect, SKB believes that the work of the Committee on Environmental Objectives on a revision of the subgoals for achieving the national environmental quality objectives within a generation should be taken into account /8-8/. The Committee concludes in defining the Riksdag's adopted environmental objective of a safe radiation environment that a final disposal of spent nuclear fuel comprises one of the most important elements in the environmental work, and that the work with final disposal of spent nuclear fuel must continue. They do not define any particular objective for management of spent nuclear fuel, but refer to the fact that it is covered by general objectives regarding a safe radiation environment, plus the provisions of the Nuclear Activities Act.

National quality objectives

In April 1999, the Riksdag adopted 15 national environmental quality objectives. They describe properties which the natural and cultural environment must possess for ecologically sustainable development. The environmental quality objectives are defined and explained with subgoals. In June 2000, the Committee on Environmental Objectives submitted proposals for subgoals and measures to achieve them to the Government.

8.2.2 Information, dialogue and consultation

In parallel with the general siting and feasibility studies, SKB has stepped up its efforts for information, dialogue and consultation on the siting work. This applies at both the national and local levels.

At the municipalities where feasibility studies are being conducted there are local information offices to which people can come with questions and viewpoints. SKB has also contacted organizations, companies and others and arranged seminars and exhibitions to furnish information on its activities and opportunities for direct dialogue. In SKB's opinion, this, along with the efforts of others – municipalities, authorities, media, interest groups and individuals – has created good opportunities and forms for future consultations.

Interest on the part of the media in the nuclear waste issue, and particularly the siting process, has increased in recent years. In general, a trend can be observed from a previous often fragmentary reporting of individual events towards a more comprehensive coverage with a large element of debate on fundamental issues. SKB interprets this as a maturing of the nuclear waste debate in society, without the diversity of opinions having diminished as a result. What has contributed most to this trend is the fact that the siting work has, via the feasibility studies, passed from planning to concrete activities at several places in the country.

In conjunction with the commencement of the site investigations, SKB request a statement from the concerned county administrative boards regarding the siting of a deep repository. The consultation thereby falls under the provisions of the Environmental Code. SKB's view of the upcoming consultations is described in Chapter 13.

8.2.3 Municipalities

No formal permits are required for SKB to conduct a feasibility study in a municipality. In view of the intention to conduct an open siting process on a voluntary basis, SKB has nevertheless chosen to initiate discussions with the municipalities at an early stage. The basic requirements for a feasibility study to be of interest for SKB have been that the municipality has been preliminarily judged to possess good technical prospects for a siting, and that the municipality has not objected to participate in the siting process. The discussions has, in a total of eight cases, led to feasibility studies has varied from case to case. Table 8-1 summarizes the crucial municipal decisions, and more detailed information is found in the feasibility studies' final reports /8-9 to 8-16/. A comprehensive account of the activities of the different municipalities has also been presented by the Government's special advisor in the nuclear waste field /8-17/.

The municipalities have been actively involved in the execution phase of the feasibility studies. They have established their own organizations, whose main functions are to handle contacts with SKB, the regulatory authorities and other parties, and to take responsibility for information to and dialogue with municipal residents. This work has involved the municipalities' political bodies, civil servants and, to a varying degree, other local stakeholders and the general public. Somewhat different solutions have been chosen when it comes to work forms and organization. This may reflect political differences, previous experience with nuclear activities, the established division of labour between politicians and civil servants, and, not least, the dates and timetables for the different feasibility studies. Since 1995, the municipalities can obtain financial assistance from the Nuclear Waste Fund (via SKI) for their activities in connection with the feasibility studies.

SKB has delivered preliminary final reports from the feasibility studies to the municipalities in order to give all stakeholders an opportunity to discuss the contents and offer their viewpoints. SKB has taken into account viewpoints from the municipality and others in the final reports. The municipalities have circulated the preliminary final reports and underlying background material to local stakeholders and, in some cases, to hired experts for review and comment. Viewpoints in various forms have then been conveyed to SKB, which takes them into account in feasibility study's final report and/or in the continued work.

The municipalities are reviewing bodies for the RD&D programmes, and will thereby be given an opportunity to review this account and offer viewpoints to SKI. After the Government's decision regarding this account, the municipalities where SKB proposes site investigations are expected to decide whether SKB shall be allowed to proceed with the siting work and carry out site investigations. With the start of the site investigation phase, consultation in accordance with the Environmental Code also commences, where the municipalities play an important role.

Table 8-1. Municipalities' decisions on feasibility studies

Municipality	Decision
Storuman	June 1993, municipal council (24 yes, 12 no)
Malå	November 1993, municipal council (14 yes, 14 no)
Östhammar	June 1995, municipal council (36 yes, 12 no)
Tierp	June 1998, municipal council (unanimous)
Älvkarleby	June 1999, municipal council (30 yes, 1 no)
Nyköping	Municipal council decision has not been taken
Oskarshamn	October 1996, municipal council (38 yes, 5 no)
Hultsfred	May 1999, municipal council (unanimous)

8.2.4 County administrative boards, regional consultations

In its decision regarding RD&D-Programme 95 /8-5/, the Government stated that the county administrative boards in the counties affected by feasibility studies should assume a coordinating responsibility for the contacts with municipalities and state authorities that are needed for SKB to compile material for an EIA.

In the counties where SKB has conducted feasibility studies (Uppsala, Södermanland and Kalmar counties), the county administrative boards coordinate the activities included in the site selection process. This is done by e.g. arranging meetings on a regional level. The forms for these meetings vary, as do which parties participate, see the appendix. But the concerned municipalities, SKI, SSI, the Government's special advisor and SKB are represented at all of them.

8.2.5 Regulatory authorities and ministry

SKI and SSI

SKI's and SSI's roles as regulatory authorities in the field of nuclear waste are described in Chapter 3. One of SKI's functions is to take responsibility for the review of SKB's RD&D programmes and prepare these matters for the Government's decision. In its statement to the Government on RD&D-Programme 98 /8-18/, SKI found that the programme satisfied the requirements in the Nuclear Activities Act. Furthermore, SKI specified points where it was proposed that the Government require SKB to submit additional material before site investigations are commenced. The proposals were confirmed via the requirements which the Government subsequently stipulated in its decision, see Chapter 3.

Aside from the handling of the RD&D programmes, the siting process does not include any activities that require permits or formal review by the regulatory authorities until the point when siting applications are to be submitted. SKI and SSI are nevertheless involved in several ways in the ongoing work. This is particularly true in conjunction with the feasibility studies, where the authorities have a special role in furnishing information and expert knowledge to the municipalities and the public. The authorities also participate actively in the regional consultations that take place under the auspices of the county administrative boards, as well as in many other contexts where different aspects of the siting question are brought up for discussion.

Regulations that have recently been issued by the authorities, or have been proposed, have an important bearing on SKB's siting work. SSI's regulations on the final management of spent nuclear fuel /8-19/ state that a repository for spent nuclear fuel or nuclear waste shall be designed so that the annual risk of harmful effects after closure does not exceed one in a million for a representative individual in the group exposed to the greatest risk. The radiation protection requirement which the deep repository has to satisfy is thereby quantified. The regulations further state that final management shall be implemented so that biodiversity and the sustainable use of biological resources are protected against the harmful effects of ionizing radiation.

SKI recently submitted a proposal for regulations on safety in the final disposal of nuclear waste. There it is asserted that safety shall be based on a system of passive barriers in such a way that a defect in any of the barriers may not appreciably degrade the safety of the repository. It is further stated that features, events and processes of importance for the safety of a repository after closure shall be analyzed before the repository is built, before it is put into operation and before it is closed.

The Government's special advisor

In May 1995 the Government appointed a national coordinator in the nuclear waste field, whose task was to coordinate the information and research activities deemed necessary by the municipalities affected by the siting work. As of May 1999, this function is called special advisor in the nuclear waste field and is more closely tied to the Government Offices. The special advisor is supposed to co-ordinate educational and information activities between concerned parties and maintain close contact with the organizations that wish to participate in the siting process. The special advisor is also supposed to help to convey the Government's view in matters related to management and disposal of spent nuclear fuel to those affected by the siting process. Other duties include research and documentation /8-17/.

KASAM

KASAM – the Swedish National Council for Nuclear Waste – was established in 1985 as an independent expert committee and advisory body to the Government and the regulatory authorities in nuclear waste matters. KASAM's members represent specialized knowledge within a number of fields of importance to radioactive waste disposal. One of the committee's tasks is to make an assessment of the state of knowledge in the field of nuclear waste every three years /8-20/. Furthermore, KASAM issues its own statements of comment to the Government on SKB's RD&D programmes. In its statement of comment on RD&D-Programme 98 /8-21/, KASAM found that the programme satisfied the requirements of the Nuclear Activities Act and otherwise offered a number of viewpoints on method and site selection questions.

8.3 Points of departure for the site investigation phase

SKB has now carried out feasibility studies in a total of eight municipalities. Several areas have been identified where the bedrock is judged to be potentially suitable for a deep repository. The feasibility studies have indicated a number of promising siting alternatives in terms of the technical, environmental and societal prospects of establishing and operating the deep repository as well.

In two of the municipalities, Storuman and Malå, referendums have been held to ascertain public opinion regarding further participation in the siting process for the deep repository. In both cases the referendums resulted in a rejection of further participation. SKB's conclusion is that the local support that is necessary for executing a siting process is insufficient in these municipalities.

In SKB's judgement, this leaves six municipalities in the selection pool for the site selection phase: Älvkarleby, Tierp, Östhammar, Nyköping, Oskarshamn and Hultsfred. They are located in three regions: Northern Uppland, Södermanland and Småland. Geologically these regions are completely dominated by crystalline basement, but they represent different variants of the crystalline basement and thereby a variation in geological conditions. The selection pool offers varying conditions when it comes to environmental and societal siting factors as well.

RD&D-Programme 98 /8-6/ contained an overview of the extensive body of siting data that was available at that time. One way to describe what has emerged since then and sum up the current situation is to compare the work plan up to 2001, according to RD&D-Programme 98, with the actual outcome. Table 8-2 quotes the planned measures given in RD&D-Programme 98, along with comments on the current situation. A more complete overview of the geoscientific siting data is given in Chapter 9.

Table 8-2. Background material for the site investigation phase - current situation compared with work plan in RD&D-Programme 98

Plan in RD&D-Programme 98 *(quote, page 65)*	Current situation
"An important goal for the next few years is to be able to commence site investigations at a couple of sites in the country. To achieve this we plan to do the following during the period up to 2001:	
• *Report the results of regional siting studies for all counties in Sweden except Gotland*	Completed /8-22/
• *Report the results of the feasibility studies in Nyköping, Östhammar, Oskarshamn and Tierp*	Results of feasibility studies in Östhammar, Nyköping and Oskarshamn reported /8-11, 12, 13/ Results of feasibility study in Tierp reported in preliminary final report /8-14/
• *Conduct and report the results of at least one more feasibility study*	Two additional feasibility studies, Älvkarleby and Hultsfred, have been conducted The results of both have been reported in preliminary final reports /8-15, 16/
• *Submit an integrated account of all siting data for the deep repository*	Presented in this report, Part III.
• *Present programmes for geoscientific site investigations and site evaluation with criteria*	Completed, see /8-23, 24/ and Chapter 13
• *Choose at least two sites for site investigations and submit site-specific investigation programmes*	SKB's choice of sites is described in this report, Chapter 12. Site-specific investigation programmes are being produced during 2001, in consultation with concerned municipalities, see Chapter 14.
• *Submit a new comprehensive assessment of long-term safety and have it reviewed by international experts*	SR 97 submitted, see /8-25/ and Chapter 7.
• *Continue the work of supportive research and development on the main method and alternative methods for managing and disposing of spent nuclear fuel.*	SKB's positions regarding method are presented in Part II of this report. Research and development is under way according to plan, and a progress will be given in the next regular RD&D programme.
• *Continue the work of technology development and planning/design of encapsulation and deep disposal*	Proceeding according to plan, progress report in next regular RD&D programme.
• *Compile supporting material for an application for a permit to build an encapsulation plant"*	Proceeding according to plan, progress report in next regular RD&D programme.

SKB evaluates the siting prospects with regard to

- Bedrock
- Industrial establishment
- Societal aspects

In the feasibility studies, data have been consistently compiled and analyzed from the point of view of siting factors grouped under the headings safety, technology, land and environment, and society. This subdivision into subject areas has suited the purpose of the feasibility studies. In preparation for the overall evaluation of the screening data, however, SKB has reworked the material into a structure that better matches the various other requirements and premises that govern both SKB's own evaluations of the material and other parties' review thereof. The requirements which the deep repository must satisfy can be described as follows:

- **Bedrock**
  The properties of the bedrock determine the prospects of long-term safety and the technical prospects for building and operating the underground portions of the deep repository. The safety requirements and the requirements these in turn lead to on the bedrock distinguish the deep repository from other rock facilities. SKB has determined and presented requirements on the bedrock, advantageous conditions (preferences) and methodology and criteria for determining whether these requirements and preferences are fulfilled /8-23/. We believe that this material should be used in the continued work of selecting sites for site investigations, and in order to evaluate sites during the site investigation phase.
- **Industrial establishment**
  The deep repository project must be able to be implemented as an industrial project. This means that construction and operation must be technically feasible, that resources must be available, and that all requirements on occupational safety and protection of man and the environment must be met. In these respects the deep repository does not differ essentially from any other industrial activity. Grounds for evaluation and experience can therefore largely be taken from other siting projects.
- **Societal aspects**
  In order for the deep repository project to be realized, it must have political and popular support. The concerned municipality, the Environmental Court and the Government must approve of the siting. In practice, this means that local and national elected officials, as well as the public, and particularly local residents, must have confidence in SKB and the nuclear waste programme.

In the following chapters, the siting factors and the selection pool have been consistently structured and evaluated on the basis of the three categories of evaluation grounds mentioned above. Figure 8-3 shows how the siting factors applied in the feasibility studies interact with these three categories.

Feasibility studies	**This report**		
	Bedrock	Industrial establishment	Societal aspects
Safety	Long-term safety		
Technology	Rock facilities - construction, operation, working environment	Surface facilities, transport and infrastructure, working environment	
Land and Environment		Land use, protection interests, environmental impact	
Society		Resources - labour, suppliers, service	Decision-making process, public opinion

***Figure 8-3**. Structure for siting factors in feasibility studies and in this report.*

The assessment which SKB makes of the selection pool prior to the choice of sites for investigations with regard to bedrock, industrial establishment and societal aspects is summarized in Table 8-3. As mentioned previously, it is SKB's opinion that the selection pool is good enough, in terms of scope and quality, to proceed to the site investigation phase. SKB further regards a continued open siting process based on voluntary participation by municipalities and an active dialogue between SKB and all involved parties as the basis for a successful siting of the deep repository.

Table 8-3. Situation prior to the start of the site investigation phase

Bedrock	In five of the six municipalities included in the selection pool, the feasibility studies have identified areas where the bedrock offers good prospects for satisfying the safety requirements. Both SKB and the regulatory authorities have concluded that the feasibility studies do not permit the areas to be ranked with regard to the bedrock. However, it is possible to make forecasts with different degrees of reliability, which can serve as instruments in the evaluation work. It is then also important to identify and evaluate the remaining uncertainties, as well as what measures in the form of drilling or other investigations are required to eliminate them.
Industrial establishment	A number of possible siting alternatives have been identified in the feasibility studies. Knowledge of the technical and environmental prospects of establishing the deep repository as an industrial activity is at this point better than knowledge of the bedrock. The siting alternatives can be ranked in certain respects, for example as regards transport options. In other respects, uncertainties remain here as well. Further research and planning work can reduce these uncertainties to a great extent.
Societal aspects	SKB's current judgement is that all the regions and municipalities included in the selection pool have potential for gaining community support. These societal aspects are of a different and more complex character than other siting factors. They can change over time, which makes them more difficult to judge.

9 Geoscientific data

SKB has been conducting investigations of the Swedish bedrock since the mid-1970s. The purpose has been to build up a general knowledge base, especially of those conditions in the bedrock that are of importance for the safety of a deep repository. The knowledge base also includes experience from other countries, including Finland, where site investigations have been done in bedrock that resembles that in Sweden. SKB and other organizations have also conducted safety assessments on several occasions. These have shown that long-term safety can be achieved for a deep repository in Swedish crystalline basement.

9.1 State of knowledge

The knowledge base concerning the bedrock and its importance for long-term safety rests in part on general geoscientific background knowledge, and in part on the results of systematic development work in the nuclear waste programme. The development work has been pursued continuously since the mid-1970s. The chief constituents have been:

Research, bedrock investigations and safety assessments

- Basic scientific/technical research, which has provided fundamental knowledge of how different parameters and processes affect the safety functions of the deep repository.
- Geoscientific investigations, which have provided knowledge of the conditions prevailing at relevant depths in Swedish crystalline basement.
- Safety assessments, which have provided an understanding of the safety-related performance of the entire system and identified important parameters.

The knowledge base also includes results from similar activities conducted in other countries that have a geological setting resembling that in Sweden, mainly Finland and Canada, but also to some extent France, Japan and Switzerland.

The results of the work have been reported regularly in the RD&D programmes. A compilation of the current body of geoscientific data is presented in a separate report /9-1/. It mentions over 700 references, which gives a picture of the scope of the research that has been conducted during the past 25 years.

Table 9-1 provides an overview of studies and major projects included in the knowledge base that has been accumulated in preparation for the selection of sites for site investigations. The overview includes studies of the bedrock on different scales and safety assessments for evaluation of long-term safety for a deep repository. The material has been used to formulate requirements and preferences regarding the rock (described in Chapter 10) and to make comparisons between areas, as well as to draw conclusions regarding the prospects of a repository in different geological settings (Chapters 11 and 12). It has also served as a basis for devising a programme for site investigations (chapter 13).

Examples are given in the following of major research projects, bedrock investigations, general siting studies, feasibility studies and safety assessments which together have provided the knowledge basis that now makes it possible to proceed to the next step of site investigations on several selected sites.

Table 9-1. Overview of geoscientific knowledge base

Source of data	Comments
Geoscientific background material (1977-)	Investigations of vital geoscientific topics, concerning e.g. tectonics, structural geology, earthquakes, hydrochemistry, ice ages and rock stresses.
Stripa Project (1977-1992)	The first large international research project in the nuclear waste field. The project tested how canisters and backfill materials perform in a realistic environment at repository depth and developed methods for investigating and modelling fracture zones and groundwater flow.
Äspö HRL (1986-)	SKB's Hard Rock Laboratory. Important tasks are geoscientific research, testing of methods for site investigations, technology development for the deep repository, information activities and training of personnel.
Investigations of study sites (1977-1985)	More or less comprehensive site investigations with deep drilling and measurement of rock properties on some ten or so sites in Sweden. Shows that sites with good geological potential can be found at various places in the country.
General Siting Study 95	Describes siting prospects on a national scale. Dismisses the Caledonides and parts of Skåne and Gotland.
County-specific general siting studies	Evaluate siting prospects in all counties with the exception of Gotland. Focus on geoscientific conditions. Indicate areas with potentially suitable/unsuitable conditions for further studies.
North-south/ Coast-interior	Describes differences of a general nature between siting in northern versus southern Sweden and on the coast versus in the interior. Shows that these differences are not crucial for the siting prospects.
General siting study of municipalities with nuclear activities	Examines the siting conditions in municipalities that already have nuclear activities. Gives the reasons for SKB's desire to conduct feasibility studies in Oskarshamn, Nyköping, Östhammar and Varberg. Dismisses Kävlinge Municipality.
Feasibility studies	Analyze the prospects in eight municipalities. Designate areas of interest for site investigations in the different municipalities. Shed light on possible consequences of a deep repository siting from a regional and local point of view. Describe possible impact on the environment. Six municipalities remain in the selection pool for further studies.
Safety assessments	Assess long-term safety for a deep repository according to the KBS-3 method. Several safety assessments, which have been developed and refined over the years, have been conducted by SKB, SKI and in Finland. In several cases, calculations have been performed with data taken from actual sites, for example from the study site programme.

9.2 Research in underground laboratories

Stripa Project

Research tunnel in the Stripa Mine with equipment for measuring groundwater flow and transport of radionuclides

When iron ore mining ceased in the Stripa Mine in the Bergslagen district of central Sweden, a comprehensive research and development programme concerning disposal of high-level nuclear waste was started instead in 1977. From the start and up to 1980, it was a joint project under the leadership of SKB and the US DOE (Department of Energy) /9-2/. It included studies of the impact on the rock of the heat generated by HLW, and development of technology for determination of the mechanical and geohydrological properties of the rock. The experiments were conducted at a depth of about 350 metres in a granite situated north of the iron ore in the Stripa Mine.

This was followed by the international Stripa Project, which was conducted as an independent OECD/NEA project under the leadership of SKB from 1980 through 1992. The project mainly embraced three areas: investigation of the bedrock from boreholes by means of hydrogeological and geophysical methods, studies of radionuclide transport with the groundwater through fractured rock, and studies of the function of the clay buffer and methodology for sealing of tunnels, shafts and boreholes /9-3/. Examples of instruments and methods that were developed in the project are borehole radar, seismic and hydraulic methods for investigating the bedrock between boreholes, and calculation methods for describing groundwater flow and nuclide transport in fractured rock. In the so-called Buffer Mass Test, the first simulation of a KBS-3 repository was performed on half-scale, yielding valuable knowledge concerning the interaction between canister, buffer and rock.

An important advantage of the Stripa Mine as a research station was that a suitable environment for the experiments (granite at a depth of about 350 metres) was available near the mine's existing tunnel system. A disadvantage was that the groundwater conditions were disturbed by the long years of mine operation.

Äspö Hard Rock Laboratory

SKB decided in 1986 to build a new research laboratory, the Äspö HRL (Hard Rock Laboratory), in a realistic and undisturbed rock environment down to the depth planned for the future deep repository. Äspö is located at Simpevarp in the municipality of Oskarshamn. The research takes place in tunnels down to a depth of about 450 metres.

Backfilling of a tunnel in Äspö HRL with a mixture of bentonite and crushed rock

Today the Äspö HRL is SKB's central resource for research, development and demonstration. Research is conducted to a large extent in international cooperation. Organizations from nine countries are currently participating in different projects. Some of the projects are partially funded by the EU.

The research at Äspö is oriented towards increasing scientific knowledge of the repository's safety margins and generating data for the safety assessment. Methods for site investigation, detailed characterization and repository construction, as well as technology for blasting/boring tunnels and canister holes, is developed, tested, evaluated and demonstrated at Äspö. Äspö thereby also serves as a "dress rehearsal" for site investigations and repository construction.

The technology for deposition and retrieval of canisters will be tested at the Äspö HRL

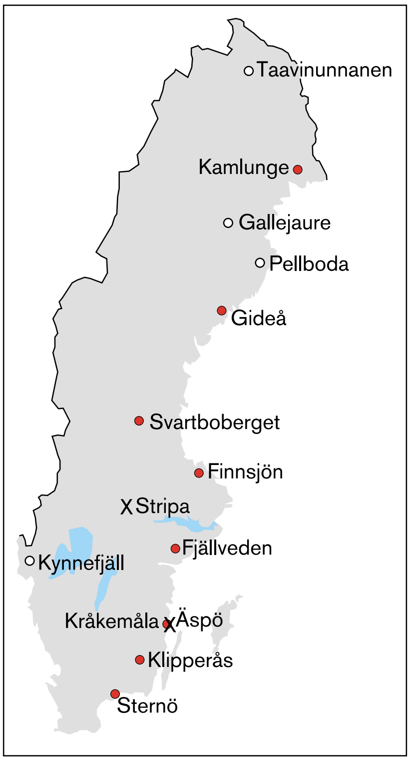
During the first ten years, extensive development and testing took place of different investigation methods and models for describing the function of the rock in the deep disposal system. The conclusion drawn from this work is that methods exist for collection of data from the ground surface and in boreholes, as well as for evaluation of a site so that its suitability for siting of a deep repository can be judged /9-4/. The work has continued with studies of radionuclide transport in the rock's fracture system and the chemical composition of the groundwater in a long time perspective.

A prototype repository is under construction where all components in the deep repository will be tested on a full scale in tunnels at repository depth for tens of years. The intention is to study the interaction between canister, buffer, rock and tunnel backfill under realistic conditions. By comparing the evolution of the prototype repository with theoretical predictions, the reliability of different models can then be evaluated. In another project, different backfill materials are being tested. In parallel with tests of barrier performance, technology is being developed for deposition of canisters and bentonite, backfilling of tunnels and retrieval of deposited canisters.

Other important tasks for the Äspö HRL are training of personnel and information to the public and decision-makers regarding technology and methods being developed for the deep repository. The research and development work is described in RD&D-Programme 98 /9-4/ as well as in the Äspö HRL's annual report /9-5/.

9.3 Study sites

Investigations of study sites and at rock laboratories have yielded knowledge of the properties of the crystalline basement



Much of the knowledge we have today on conditions at planned repository depth in the bedrock comes from the so-called study sites. Investigations of these study sites were conducted during the years 1977–1985. During this period, 85 cored boreholes with a combined length of 45 kilometres plus several hundred percussion boreholes were drilled. The boreholes were logged using different types of measurement methods. Particular emphasis was placed on determining the hydraulic conductivity of the rock and the chemical composition of deep groundwater.

Study sites have provided a broad body of geoscientific data from some ten or so sites, eight of which were investigated by means of deep boreholes /9-6 to 9-11/. The study sites represent bedrock with different types and rock with differing ages and degrees of deformation. They are situated both above and below the highest coastline. Geographically, they are spread from Blekinge to Norrbotten. Taken together, the study sites can be said to represent random samples of the majority of the geological environments in the Swedish crystalline basement that could be of interest for hosting a deep repository.

Results from the study sites have been used in many research projects and in several safety assessments. They have also comprised a basis for assessments of how conditions and properties in the bedrock vary between different geological settings and parts of the country.

The overall conclusion from the study sites is that suitable or less suitable sites are not restricted to any particular part of the country or geological setting. Instead, it is local conditions in the area and in the surrounding region that determine the suitability of an area.

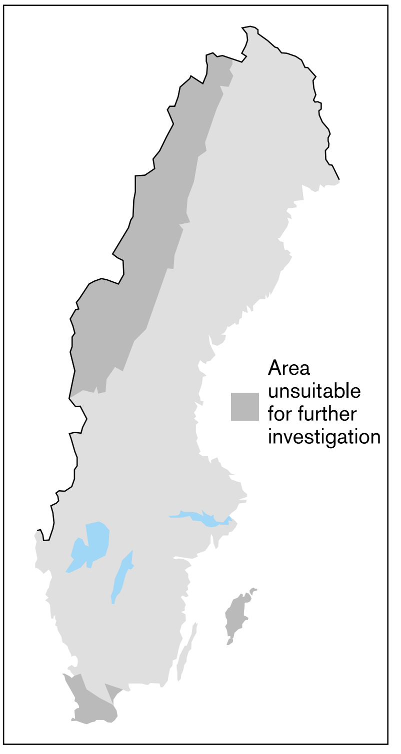
9.4 General siting studies and feasibility studies

General Siting Study 95

In 1995, SKB conducted a general siting study on a national scale to investigate the siting prospects for the deep repository /9-12/.

The study discussed what possibilities and limitations exist when it comes to judging siting prospects based on investigations performed on different scales.

Evaluations on a national scale are presented for factors of importance for both safety and technology as well as for environmental and societal factors. The study verifies that good prospects exist of finding suitable sites for a deep repository at many places in Swedish crystalline basement. The judgement is made that parts of Skåne and Gotland are unsuitable areas for a siting, mainly with reference to geological conditions.



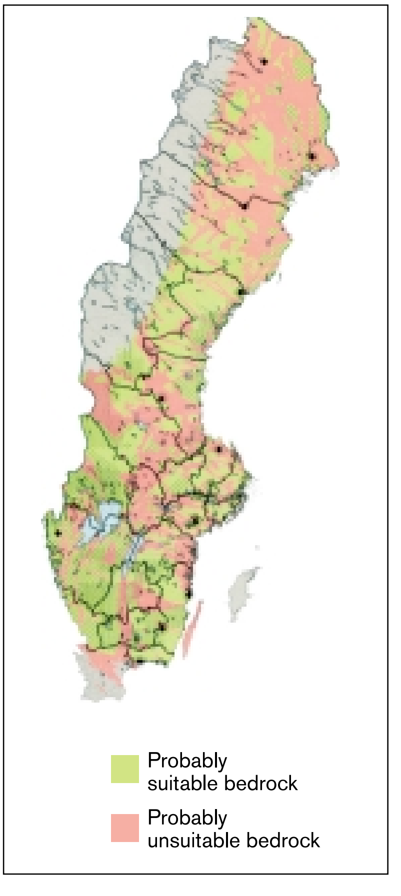
General Siting Study 95 showed that the Caledonides, Gotland and parts of Skåne have unsuitable bedrock for a deep repository

County-specific general siting studies

To provide greater detail in the prospects for siting of a deep repository in different parts of the country, SKB presented county-specific siting studies for all counties (except Gotland) during the period 1998–1999 /9-13/.

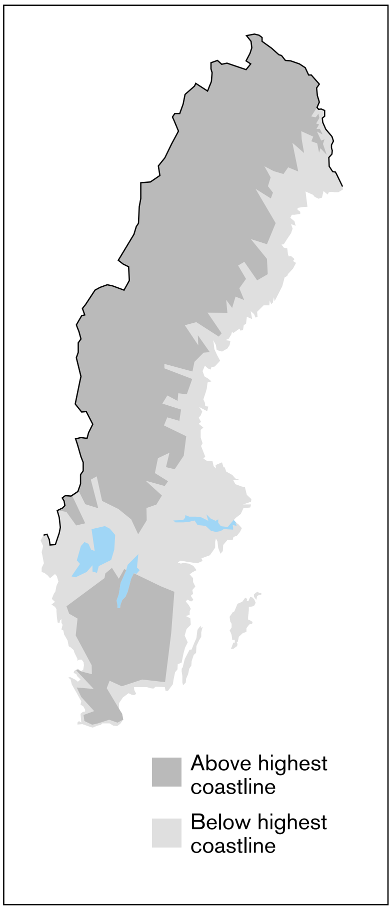
The county-specific general siting studies focus primarily on long-term safety and thereby on conditions in the bedrock. Besides geological conditions, the studies include general surveys of nature and culture protection areas, existing industry and transport facilities. In the overall geological assessment of which areas are suitable or unsuitable for further studies, bedrock composition, ore potential and occurrence of deformation zones are the most important factors. The assessments vary in reliability, since the quality of the available geological information is uneven.

The main conclusion is that bedrock of interest for further studies regarding siting of the deep repository exists in all counties studied. At the same time, there are large areas that are probably unsuitable.



County-specific general siting studies (all counties except Gotland) gave a general picture of where there may be bedrock suitable for a deep repository

Saline groundwater is common in areas below the highest coastline. SKB's studies have shown that occurring variations in groundwater salinity do not have any decisive influence on the siting prospects for a deep repository.



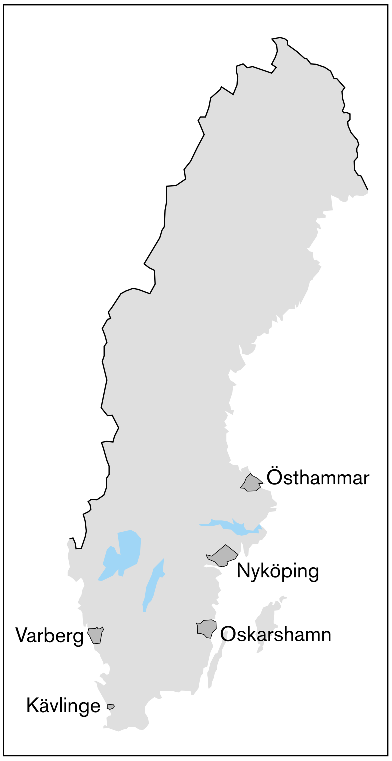
North-south/Coast-interior

SKB has also conducted a special study into the advantages and disadvantages of siting the deep repository in northern versus southern Sweden, as well as aspects of a siting on the coast versus in the interior /9-14/.

An important question in the work was to assess whether the general trends that exist in the perspectives coast-interior and north-south are of importance in relation to the local variations which are known to occur. The study indicates certain general differences. An example is that the climatic difference between north and south can influence conditions at repository depth, particularly during future glaciations. Comparisons between conditions on the coast and in the interior mainly highlight differences in groundwater conditions. For example, the occurrence of saline groundwater is common in the coastal areas, while areas above the highest coastline can be expected to have fresh groundwater to greater depth.

One conclusion drawn from the study is that it is not possible, based on the general comparisons and analyses made in the study, to recommend either the northern or the southern parts of the country with regard to prospects for a siting. Assessments of suitability must instead be based on studies of particular areas. The same conclusion applies to the comparative evaluations of siting prospects near the coast versus in the interior.

Of the five municipalities with nuclear activities, feasibility studies have been done in three: Östhammar, Nyköping and Oskarshamn.



General siting study for nuclear municipalities

A general siting study was conducted in 1995 to ascertain the prospects for siting a deep repository in one of the municipalities that already host nuclear installations /9-15/. These municipalities have the infrastructure and competence that are judged to be important factors in the siting of the deep repository. The general siting study included five municipalities with nuclear activities: Varberg, Kävlinge, Oskarshamn, Nyköping and Östhammar.

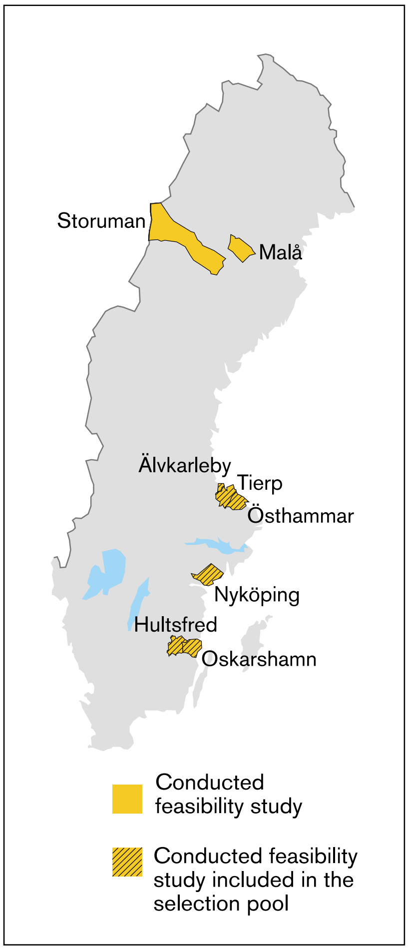
The purpose of the study was to evaluate the general prospects for a repository siting in the municipalities in question, as well as to investigate whether the existing body of geological material could be deemed adequate as a basis for conducting a feasibility study in the municipality.

The conclusions from the study of the five municipalities were that the existing body of geological material for Oskarshamn, Nyköping and Östhammar is extensive and suggests good siting prospects. The material is also judged to be well-suited as a basis for feasibility studies in these municipalities. In the case of Varberg, the study found that a general uncertainty exists regarding the suitability of the bedrock for a deep repository, in part because modern geological and geophysical maps are lacking for large parts of the municipality. SKB nevertheless considered it desirable that Varberg be included in the selection pool so that a feasibility study could be conducted to determine its suitability. However, the municipality decided not to proceed with the matter. In the case of Kävlinge, the study concluded that the geological and technical conditions are not suitable for a deep repository.

Feasibility studies

Since 1993, SKB has conducted feasibility studies in eight municipalities: Storuman, Malå, Östhammar, Nyköping, Oskarshamn, Tierp, Älvkarleby and Hultsfred /9-16 to 9-23/. An account of the considerations and course of events that led to feasibility studies in these municipalities is given in Chapter 11.

After municipal referendums, Storuman and Malå have said no to further investigations, which for SKB means that the municipalities are no longer participating in the siting process. The other six municipalities remain in the selection pool for site investigations. An addition ten or so municipalities have considered feasibility studies at various stages, but decided against them.

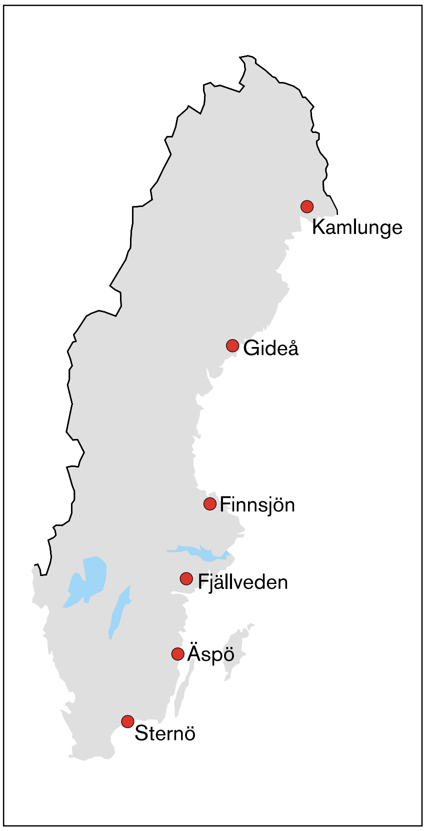


Feasibility studies have been done in eight municipalities. Six of these are included in the selection pool for choice of sites for site investigations.

The purpose of the feasibility studies has been to determine, on the basis primarily of existing material, whether prospects exist for further siting studies in the municipalities in question. Areas within each municipality deemed to be of particular interest for further studies have been identified in the final reports of the feasibility studies. Within the framework of the feasibility studies, a dialogue has been conducted with both the general public and the local government officials (municipality and county administrative board).

The conclusion drawn from the feasibility studies is that areas exist in five of the six municipalities included in the selection pool that are suitable for further studies from a geological point of view. There are also good possibilities from a technical and environmental point of view to site a deep repository in the geologically interesting sites within the studied municipalities. Results from the feasibility studies are presented in Chapter 11.

Data for safety assessments have been taken from the Äspö HRL and study sites.



9.5 Safety assessments

The safety of a deep repository for spent nuclear fuel according to the KBS-3 method was analyzed for the first time in the KBS-3 study presented in 1983 /9-24/. Since then, additional safety assessments have been carried out, both by SKB and by other organizations. With time, knowledge of the long-term performance of the repository has grown. The design of the repository has been modified and the analysis methods have been developed, in large part thanks to advances in computing. International comparisons and reviews have influenced the view of how safety assessments should be conducted and reported. The requirements of the authorities on the safety report have become more precise.

This development continues and means that a safety assessment is conducted and presented today in a somewhat different and more detailed manner than was the case for the KBS-3 safety assessment. Nevertheless, many of the conclusions from the KBS-3 report still hold up for the most part today.

A brief account of most of the major safety assessments carried out by SKB and SKI is given below.

KBS-3 study

The results of the KBS-3 study were submitted in support of an application for a permit to fuel the Forsmark 3 and Oskarshamn 3 nuclear power reactors. The repository was assumed to be designed in accordance with today's plans for the deep repository, one difference being that the canister was assumed in the KBS-3 study to be filled with liquid lead instead of having an insert of cast iron, as is planned today. Bedrock data from the study sites Fjällveden, Gideå and Kamlunge were used.

Based on a probable sequence of events, the consequences of e.g. initial canister damage, radionuclide transport with colloids, earthquakes and human intrusion were analyzed. The consequence of release to well, lake and peat bog were analyzed, among other cases.

The conclusions of the safety assessment were, in brief:

- The copper canister and buffer function were judged to remain intact for one million years.
- If canisters were damaged or had initial defects, the consequences for humans in the vicinity of the repository would be well below the limit values (similar to today's) that were issued by the radiation protection and safety authorities.

The Government found that the "method as a whole has essentially been found to be acceptable with respect to safety and radiation protection" and approved the fuelling application for the two reactors in June 1984.

Safety assessments SKB 91, SR 95 and SR 97

The SKB 91 safety assessment /9-25/ focused primarily on the importance of the bedrock for safety. Site-specific data were taken from the study site investigation in Finnsjön. The repository design was the same as that described in the KBS-3 report. The SKB report SR 95 /9-26/, which was published in 1996, comprises the beginning of a template for future safety assessments.

The SR 97 safety assessment, which is summarized in Chapter 7, is the latest in the series of assessments of a KBS-3-type deep repository. Bedrock data are taken from the study site investigations in Gideå and Finnsjön and from the Äspö HRL. One difference compared with previous safety assessments is that the fuel canister has been assumed to have an insert of cast iron. Even though SR 97 often goes much further than previous safety assessments in scope and detail, the most important conclusions are the same: initially intact canisters are expected to remain intact for more than one million years, while the consequences of releases from e.g. initially damaged canisters are expected to be very small, see further Chapter 7.

A series of assessments of the safety of different specific subsystems and their long-term performance have also been performed over the course of the years. The reasons have been to investigate details in the function of the repository or to provide grounds for comparison with other disposal methods.

SKI's safety assessments

SKI has carried out two safety assessments for the primary purpose of building up its own competence in reviewing SKB's safety assessments.

In 1991, SKI published Project-90 /90-27/, and in 1997 the results of the more extensive SITE-94 were presented /9-28/. The latter used bedrock data from surface-based investigations conducted prior to the construction of the Äspö HRL. Releases from just one copper canister with a steel insert were analyzed. A number of different conditions in the repository and host rock were studied assuming today's climate, and the consequences of expected future ice ages were also evaluated.

The results of the release calculations in SITE-94 are comparable with similar calculations in SKB's safety assessments. However, the report does not draw any conclusions regarding the safety of a KBS-3-type deep repository, partly due to the fact that the assessment was not complete, and partly because the purpose was not to reach a conclusion regarding safety.

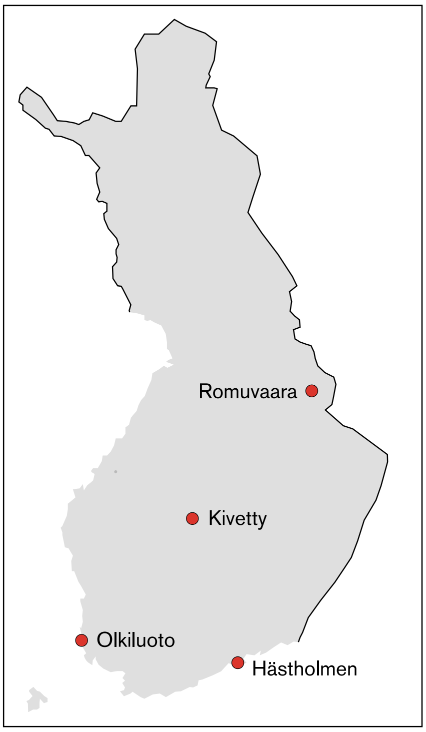
Conclusions and future assessments

Over a period of nearly 20 years, the safety of a KBS-3-type deep repository has been analyzed by SKB and other organizations, on several occasions and on the basis of data from different places. Different questions have been identified over the years for further development of the methodology and the knowledge base for the safety assessments. Where the knowledge has been incomplete, pessimistic assumptions have been made in the safety assessments regarding the performance of the deep repository. As the knowledge base has grown, more and more gaps have been filled with information, while others have been more clearly identified and delimited.

Despite the fact that the safety assessments contain many pessimistic assumptions, they all conclude that safety is ensured with ample margin.

In future safety assessments based on data from the site investigations, a body of data on the bedrock of roughly the same size as in SR 97 can be expected. The quality of the data should be better, however, since experience gained from the safety assessments performed so far has yielded knowledge of what is important to focus on in a site investigation. In coming years we can also look forward to an improved knowledge base for estimating, for example, the occurrence of initial canister defects, based on the work being conducted in the Canister Laboratory in Oskarshamn.

9.6 Finnish site investigations and safety assessments



Results of Finnish site investigations and safety assessments are of special interest for the Swedish programme, since the Finnish bedrock exhibits great similarities to our own. Four sites have been used in a recently presented safety assessment (TILA-99) /9-29/. They represent different geological settings, from very old (archaic) gneisses in eastern Finland to relatively young (about 1,600 million years old) rapakivi granite in southern Finland. The sites are situated both above and below the highest coastline /9-30 to 9-33/.

Finland has carried out a siting programme for its deep repository

Safety assessments of four selected sites showed that all satisfied the requirements

An application to site the deep repository in Olkiluoto has been submitted to the Government

The sites have been investigated by means of a large number of deep cored boreholes. There are 10–12 deep boreholes on each site, and a total of more than 30 kilometres of core drilling has been carried out. Posiva (the Finnish equivalent to SKB) has conducted extensive measurements and water samplings in the boreholes. The results have been used for safety assessment and facility design.

The Finns are also planning to use the KBS-3 method as their main alternative for final disposal of spent nuclear fuel. A number of safety assessments have therefore been conducted by Posiva for a KBS-3-type final repository. In TILA-99, as in SR 97, the canister was assumed to be of copper with a cast iron insert. The consequences of a number of more or less probable conditions in canister, bentonite, rock and biosphere are also studied in TILA-99, along with the influence of climate change.

The conclusion is drawn in TILA-99 that all four candidate sites satisfy the criteria of the Council of State (the Finnish Government) for safe final disposal of spent nuclear fuel with good margin. Despite the differences in geological setting, the safety assessment exhibits great similarities for the four sites. Another conclusion has therefore been that it is not possible to rank the sites from the viewpoint of long-term safety. Besides its own review, STUK has also commissioned an international review of the safety assessment and its technical background material. The international review was presented in the autumn of 1999 /9-34/. The conclusion was that the safety assessment can be regarded as correct in all essential respects.

STUK

Finnish Radiation and Nuclear Safety Authority

Posiva has proposed one of the four studied sites, Olkiluoto, as the site where the final repository is to be built (see section 4.8.3). Olkiluoto is a peninsula situated in the municipality of Eurajoki on the Gulf of Bothnia. There is a nuclear power plant on the peninsula, and a final repository for LILW built in rock.

The bedrock in Olkiluoto consists of highly altered veined gneisses of sedimentary origin, plus gneissic granites. Their age is 1,900–1,800 million years. Dykes of granite and pegmatite are common. The groundwater at great depth has a much higher salinity than the sea around the peninsula.

The municipality approved the siting in its statement of opinion to the Council of State in January 2000. The Council of State is expected to announce its decision during 2001. The decision must then be ratified by the Finnish parliament.

Posiva plans to build a KBS-3 repository in Olkiluoto with room for 1,800 canisters of spent nuclear fuel. This is equivalent to 40 years of operation of the four Finnish reactors currently in operation. Posiva has stated in its application that canisters from possible extended operation, as well as from any new reactors built in Finland, will also be disposed of in Olkiluoto.

10 Siting factors

Siting of the deep repository is a stepwise process with feasibility studies and site investigations. Judgements are made in each phase of whether the studied site satisfies, or has the potential to satisfy, the requirements and preferences that are made regarding the rock in terms of long-term safety and constructability. In order for siting to be possible, the site also needs to satisfy requirements and preferences relating to industrial establishment and societal aspects. This chapter describes which requirements and preferences SKB has formulated with regard to these aspects.

10.1 Requirements and preferences

The supplement to RD&D-Programme 92 /10-1/ presented the premises and factors which SKB believed should guide site selection for the deep repository. These were accepted by the authorities and the Government (see Chapter 8) and have since been guiding principles for the siting work. In parallel with the feasibility studies, SKB has continued its efforts to develop the methodology for evaluating the background material for siting. A milestone in the evaluation of the bedrock is the report "What requirements does the KBS-3 repository make on the host rock? Geoscientific suitability indicators and criteria for siting and site evaluation" /10-2/. This report presents, among other things:

- The requirements and preferences made on the bedrock on the site for the deep repository.
- How these requirements and preferences can be translated into measurable parameters and criteria that provide guidance, especially during the site investigation phase.

This chapter first provides a brief summary of the requirements and preferences on the rock that are presented in greater detail in /10-2/. This is followed by a discussion of what requirements and preferences are made on the deep repository, regarded as an industrial establishment and a societal phenomenon.

The terms requirement and preference are defined here as follows:

Requirements must be satisfied. Satisfied preferences offer advantages

- Requirements are absolute conditions that must be satisfied. They refer to actual conditions and remain the same throughout the siting process. If it is found at any point that a requirement cannot be satisfied on a site, the site must be judged to be unsuitable.
- Preferences are conditions that ought to be, but do not have to be, satisfied. Many preferences can be formulated, and satisfying all of them is not realistic. A satisfied preference can offer advantages such as larger safety margins, simplified repository construction, lower environmental impact or lower costs.

It is important to distinguish between the above concepts, particularly when it comes to the rock and the prospects of long-term safe disposal. The requirements on the rock are absolute; if they are not met on a site, the site cannot be considered for the repository. But many of the factors that have to be taken into account with regard to the rock have the character of "advantages/disadvantages", and can be translated into preferences of differing weight.

For the deep repository as an industry, there are basic requirements which stem from the laws that govern industrial establishments. For example, it is not possible to locate the deep repository's industrial activity on certain stretches of coast that are protected by law. Since it is judged possible from a purely technical standpoint to build a deep repository at many places in the country, many other siting factors have the character of preferences.

For the deep repository as a community phenomenon, there is the requirement that the concerned municipality must give its permission. There must also be national and scientific support for the siting.

10.2 Bedrock

The key function of the deep repository is to isolate the spent nuclear fuel so that it never poses a risk to man or the environment. The requirements and preferences that exist regarding the bedrock are described below. The feasibility studies provide limited opportunities to check whether these requirements and preferences are satisfied. It is not until test boreholes drilled during the site investigation phase deliver data from repository depth that most requirements and preferences can be coupled to concrete criteria. The final evaluation of safety is done in the safety assessment. The requirements and preferences do not in any way take the place of the integrated safety assessment. They do, however, provide good guidance on the suitability of a site until data are available for a safety assessment. Certain requirements cannot be verified until detailed characterization is carried out in the construction phase. This applies to requirements that pertain to the conditions around individual deposition holes, which can be handled by detailed adjustment of the repository's layout.

Criteria

Typical values that can be used to judge whether a site satisfies requirements and preferences

Long-term safety

Requirements and preferences pertaining to the long-term safety of a deep repository stem from the Nuclear Activities Act and the Radiation Protection Act, as well as the regulations issued by the safety authorities.

The Nuclear Activities Act prescribes generally that nuclear activities shall be conducted in a safe manner. The Radiation Protection Act prescribes that "anyone who conducts activities involving radiation shall, according to the nature of the activities and the conditions in which they are conducted, take the measures and precautions required to prevent or counteract injury to people and animals and damage to the environment". The laws lay down the frames, but do not give any concrete directions regarding individual requirements on barriers in a deep repository.

SSI has issued regulations on the final management of spent nuclear fuel /10-3/. There it is prescribed that a repository for spent nuclear fuel or nuclear waste shall be designed so that the annual risk of harmful effects after closure does not exceed one in a million for a representative individual in the group exposed to the greatest risk. The radiation protection requirement is thereby quantified. The regulations further state that final management shall be implemented so that biodiversity and the sustainable use of biological resources are protected against the harmful effects of ionizing radiation.

SKI has drafted regulations on safety in the final disposal of nuclear waste. They are currently being circulated for comment. There it is asserted that safety shall be based on a system of passive barriers in such a way that failure of any of the barriers may not appreciably degrade the safety of the repository. It is further stated that features, events and processes of importance for the safety of a repository after closure shall be analyzed before the repository is built, before it is put into operation and before it is closed. In a proposal for general recommendations, SKI also proposes that "The site of a final repository in rock and the depth of the repository should be chosen so that the rock provides sufficiently stable and favourable conditions so that the repository's barriers will function as intended for a long enough period of time. The relevant conditions are primarily related to temperature, water flow rate, rock mechanics and geochemistry."

Functional requirements on the repository and its components (the protective barriers) can be derived from the overall safety requirements and the general structure of the repository. These functional requirements can in turn be translated into requirements and preferences regarding the rock, based on knowledge of how different conditions and processes in the rock affect the properties and function of the repository. The requirements and preferences that can be formulated for the rock in this manner can in some cases be broken down into values of individual physical or chemical parameters. Table 10-1 illustrates with two simple examples how explicit requirements on the environment in the bedrock hosting the repository have been derived from overall functional requirements on the bentonite barrier and the canister.

In /10-2/, SKB systematically goes through a large number of different properties related to the geology, mechanical state, temperature distribution, groundwater flow, groundwater chemistry and transport properties of the bedrock. Based on function requirements on the barriers, requirements and preferences are then formulated regarding the properties that influence function. These properties are presented below as tables with requirements and preferences regarding rock composition and structure (Table 10-2), groundwater composition (Table 10-3) and retardation in connection with the transport of radionuclides (Table 10-4). Table 10-5 presents geological factors coupled to the "investigability" of the site, i.e. the possibility of judging the bedrock at great depth or between boreholes on the basis of data from the ground surface or in boreholes. These factors are indirectly significant, since they influence the reliability of the assessments and analyses that can be made of long-term safety.

Rock construction and operation

Requirements and preferences on the rock in connection with construction and operation of the repository's underground rock facilities stem partly from occupational safety and working environment considerations and partly from the

Table 10-1. Two examples of how requirements and preferences regarding the rock can be derived from fundamental functional requirements on the repository's barriers

Fundamental functional requirements on subsystem	
Example 1: The bentonite buffer shall contribute to long-term isolation and retardation	Example 2: The canister shall retain its isolating capacity in the long term
…which lead to	
Requirement that the buffer should develop and preserve a certain swelling pressure.	Requirement that the deposition holes not be deformed so that the canister is damaged.
…which is influenced by	
The chemical composition of the surrounding groundwater, including salinity.	The presence of extensive fracture zones in which major rock movements can take place.
…which results in the following requirements/preferences regarding the rock	
The total salinity of the groundwater may not exceed 100 g/l. Furthermore, the concentration of $[Ca^{2+}]+[Mg^{2+}]$ must be greater than 4 mg/l, since then it is simple to show that the clay gel does not erode and form colloids.	Deposition tunnels and deposition holes may not pass through or close to regional or local major fracture zones. Preference for few local minor fracture zones, since they limit the number of possible canister positions in a given area. If this preference is not satisfied, a larger rock volume has to be utilized.

Swelling pressure
The bentonite buffer swells when it absorbs water, exerting pressure on canister and rock

Colloid
Particles that are so small that they do not sink to the bottom in e.g. water

Plastic shear zone

Deformation zone formed as a result of plastic deformation, i.e. under high pressure and high temperature at great depth

Length of fracture zones

Regional, more than 10 km

Local major, 1-10 km

Local minor, 10 m-1 km

Thermal conductivity

The rock's capacity to dissipate heat from the deposited canisters

Coefficient of thermal expansion

A measure of how the bedrock expands when the temperature rises

Table 10-2. Requirements and preferences with regard to rock composition and structure

Factor	Requirement	Preference	Comment
Rock type	The rocks types in the deposition area may not have ore potential, i.e. consist of minerals so valuable that they might justify mining at a depth of hundreds of metres.	Commonly occurring rock types.	The presence of ore poses a risk of future intrusion in the repository. An ordinary rock type reduces the risk that the bedrock on the site may be considered valuable in the future.
Structures	Regional plastic shear zones shall be avoided unless it can be shown that the properties of the zone do not deviate from the rest of the rock.		Veins within the zone may have developed into water-bearing fracture zones which may be associated with reduced mechanical strength.
	It must be possible to position the repository with respect to the fracture zones on the site. This means a.o. that: - deposition tunnels and deposition holes for canisters must be able to be positioned so that they are not intersected by, or lie too close to, regional and local major fracture zones. - deposition holes shall be able to be positioned so that they are not intersected by identified local minor fracture zones.	Low frequency of local minor fracture zones and fractures.	Fracture zones generally have higher permeability and lower strength than the rest of the rock. From a mechanical viewpoint, greater future deformations can generally be expected in large (long) fracture zones than in small (short) ones. Fractures have higher permeability and lower strength than intact rock. The presence of large areas with good rock quality and low permeability facilitates the layout of the repository.
Thermal properties		The rock should have higher thermal conductivity than 2.5 W/(m,K) and the undisturbed temperature at repository depth should be lower than 25°C.	The parameters influence how the repository is to be designed in order to limit the maximum temperature on the canister surface. If the preference is satisfied, repository configuration is simplified.
		The coefficient of thermal expansion should have normal values for Swedish bedrock (i.e. within the range 10^{-6} to 10^{-5} K^{-1}) and not differ markedly between the rock types present in the repository area.	At normal values good understanding exists of how the heat from the deposited canisters affects the rock.

Table 10-3. Requirements and preferences with regard to groundwater composition

Factor	Requirement	Preference	Comment
Oxygen	The groundwater at repository level may not contain dissolved oxygen.		Dissolved oxygen in the groundwater leads to canister corrosion. Absence of dissolved oxygen is indicated by negative Eh, presence of Fe(II) or presence of sulphide.
Salinity	The total salinity (TDS) of the groundwater must be less than 100 g/l at repository level.		Very high salinities can damage the long-term function of the buffer (swelling capacity). In comparison it can be mentioned that seawater has a salinity of 35 g/l (TDS).
Other chemical properties		Undisturbed groundwater at repository level should have a pH in the range 6-10, a low concentration of organic compounds ([DOC] lower than 20 mg/l), a low colloid concentration (lower than 0.5 mg/l), low ammonium concentrations, some content of calcium and magnesium ($[Ca^{2+}]+[Mg^{2+}]$ greater than 4 mg/l).	The stipulated ranges entail conditions where good understanding exists of how the groundwater affects the different barriers in the repository.

Eh

Redox capacity, i.e. capacity to consume an oxidant, e.g. oxygen

TDS

Total Dissolved Solids (a measure of total salinity)

pH

Measure of acidity. The lower the pH, the higher the acidity. pH = 7 is neutral, e.g. in drinking water

DOC

Dissolved Organic Carbon. Total organic compounds dissolved in water.

need for rational construction and operation of the facilities, using known technology and without unacceptable environmental impact. To these are added functional requirements, which have the character of technical specifications on the facilities and structures to be built.

Table 10-6 provides a summary of important requirements and preferences regarding rock construction and working environment. The requirements are the same as for other rock facilities. The regulations of the National Board of Occupational Safety and Health lay down specific requirements on the execution of rock excavation and blasting work. The radiation protection requirements for repository operation stem from the Radiation Protection Act and do not differ from those that apply to other nuclear installations. There is a preference that the bedrock and the groundwater should not have a composition that can lead to high radon concentrations in the repository's rock facilities, since extra ventilation or other special measures may then be required to reduce the concentrations to levels that are acceptable from an occupational health viewpoint.

The fundamental requirements on a safe working environment and technical constructability entail that stable tunnels and shafts must be able to be excavated and that rock excavation must be able to be accomplished with full control of stability and water seepage. The properties of the rock, regarded as a construction medium, determine constructability. Important properties of the rock are strength, loads (rock stresses) and water conductivity. In combination with e.g. repository depth and tunnel dimensions, these properties determine what building methods can be used, as well as the need for stabilization and sealing of the excavated rock chambers. One requirement is that the strength of the rock, the fracture geometry and the initial rock stresses may not be such that they give rise to serious stability problems around tunnels or deposition holes within the deposition area. It is, however, difficult to derive requirements on individual properties (e.g. rock stresses) from this requirement. Otherwise there are only a

Transport resistance
A measure of the ease with which radionuclides can move in the rock, which is dependent on the Darcy velocity, the flow distribution and the flow-wetted surface

Darcy velocity or flux
A measure of groundwater flow

Rock matrix
The portion of the rock mass located between fractures

Matrix diffusivity
The capacity of the rock matrix to withhold radionuclides from transport with the flowing groundwater

Matrix porosity
Fraction of cavities in the rock matrix

Hydraulic gradient
The change in the hydraulic head per unit distance, i.e. the slope of the groundwater table

Table 10-4. Requirements and preferences with regard to retardation in the transport of radionuclides through the bedrock

Factor	Requirement	Preference	Comment
Retardation of radio-nuclide transport through the rock	Retardation in the rock together with other barriers should lead to compliance with SSI's regulations.	Transport resistance should be greater than 10^4 y/m.	A significant retardation of important radionuclides in the rock is a preference.
Hydraulic conductivity		It is an advantage if a large portion of the rock mass in the deposition area has a conductivity (K) that is less than 10^{-8} m/s.	Low conductivity contributes to the retardation of radionuclides in the rock.
Flow rate		That it be possible in a large portion of the rock to find canister positions where Darcy velocity is lower than 0.01 m/y on a canister hole scale.	Lower fluxes entail greater retardation of important radionuclides.
Properties of the rock matrix		Matrix diffusivity and matrix porosity should not be much lower than the value ranges used for the SR 97 safety assessment (a factor of 100 or more). The maximum accessible diffusion depth should at least exceed a centimetre or so.	Within the given value ranges, there is potential for radio-nuclides to diffuse into the immobile water in the micro-pores and microfractures in the rock. This retards or prevents further transport of these radionuclides.
Hydraulic gradient		It is an advantage if the local hydraulic gradient is lower than 1% at repository level, (although lower values do not provide any additional advantage).	The hydraulic gradient drives the groundwater flow.

Table 10-5. Requirements and preferences with regard to investigability

Factor	Requirement	Preference	Comment
Soil cover		High proportion of exposed rock and otherwise thin soil cover.	Not a safety-related prefer-ence, but important because it makes it easier to judge the bedrock at repository depth from the ground surface.
Homogeneity		Homogeneous bedrock.	Homogeneous bedrock facili-tates characterization of the rock and calculations of the performance and impact of the repository, both in space and in time.

Table 10-6. Requirements and preferences with regard to rock construction and working environment

Factor	Requirement	Preference	Comment
Stability in rock facilities	Rock strength, fracture geometry and initial rock stresses may not be such that serious stability problems arise around tunnels or deposition holes in the deposition area.	Normal strength and deformation properties provide advantages.	Deposition holes and tunnels must be possible to execute to specification and be durable. Requirements on occupational safety must also be able to be met.
Water-bearing zones		Fracture zones that need to be passed during construction should have low permeability (a transmissivity (T) that is lower than 10^{-5} m^2/s).	Passage of zones should be able to take place without abnormal technical problems.
Radon		Low levels of radon and radium in groundwater and low concentrations of uranium-bearing minerals in the rock.	There are limits on what radon concentrations can be accepted in the rock facility from an occupational health viewpoint.

Transmissivity

A measure of permeability which is preferably used to describe the capacity of fracture zones to allow groundwater to pass through them

Radon

A colourless and odourless radioactive inert gas formed by decay of radium

few preferences from the rock construction viewpoint, since adaptability to different rock conditions is considerable. In general, conditions that are suitable from a safety point of view are also favourable from the viewpoint of construction and operation.

Construction analyses for the deep repository require, in the same way as safety assessments, site-specific geological information and data from borehole investigations. In early stages there is thereby also the same need for preliminary assessments based on general knowledge and surface-based knowledge. The difference, compared with the safety assessment, is that these judgements can often be supported by actual experience from existing rock facilities.

Under what circumstances should investigations on a site be discontinued?

An overall safety assessment and an overall construction analysis comprise essential background material in an integrated assessment of whether a site is suitable. The site is only accepted if it is possible to show in the safety assessment that the deep repository can satisfy the regulatory authorities' safety requirements. During a site investigation, when measurement data have been obtained from repository depth but before the overall assessment has been carried out, criteria are used to check whether the above requirements and preferences can be satisfied.

Ore

A mineral concentration that is economically workable

The following criteria are so important that the site investigation should be discontinued and another site chosen if they cannot be met:

Industrial minerals

Non-metallic minerals used for industrial purposes, such as manufacture of porcelain and glass

- If large deposits of ore minerals or valuable industrial minerals are encountered within the repository area, the site should be abandoned.
- If the repository cannot be positioned in a reasonable manner (if it would have to be split up into a very large number of parts) in relation to regional plastic shear zones, regional fracture zones or local major fracture zones, the site should be abandoned. During the site investigation, the repository is adapted more precisely to the fracture zones identified at that time. Suitable

respect distances to major identified regional and local major fracture zones can only be determined site-specifically, but it is assumed that a distance of at least several tens of metres to major local zones and at least 100 metres to regional zones is appropriate.

- If an integrated rock-mechanical analysis shows that the repository cannot reasonable be designed in such a way that extensive and general stability problems in rock facilities can be avoided, the site should be abandoned. Extensive problems with "core discing" of drill cores give reason to suspect such problems.
- If oxygen-free conditions cannot be proven, the site should be abandoned. The groundwater at repository depth must be free from dissolved oxygen. Satisfaction of this requirement shall be indicated by at least one of the following indicators: negative Eh values, occurrence of iron (Fe^{2+}) or occurrence of sulphide. If none of the indicators can clearly indicate the absence of dissolved oxygen, a more thorough chemical assessment is required.
- If measured total salinities (TDS = Total Dissolved Solids) at repository level are higher than 100 g/l, the site should be abandoned. Occasional higher values can be accepted if it can be shown that the water is located in areas that can be avoided and that the water will not be able to flow to the repository area.

Besides these direct disqualifying criteria, the suitability of the site can be questioned if a large fraction of the rock mass between fracture zones has a hydraulic conductivity greater than 10^{-8} m/s.

10.3 Industrial establishment

SKB's view of a number of siting factors coupled to the deep repository as an industrial project is presented in the following. The fundamental principle is that the selected site must provide good conditions for practical execution of the deep repository project.

Land use and environmental interests have been taken into account in the feasibility studies. All siting alternatives that are put forth are therefore deemed to be feasible from this aspect. There are, however, differences entailing that different degrees of consideration must be given in site investigations. The feasibility studies have also described the technical feasibility of establishing the deep repository's facilities and the site operations located on the surface, as well as the transportation system. Here, however, a great deal of study and consultation remains in order to obtain detailed plans for the different siting alternatives. This is particularly true of inland locations, where the possibilities for overland goods transport to the deep repository must be clarified in detail in preparation for a possible siting application.

Facilities and activities on the surface

The deep repository's facilities and activities on the surface require land for operating areas, rock spoil heaps, traffic connections, etc. The facilities must be sited on land that is suitable for the purpose, and the siting must not conflict with good management of land and water. SKB's premises for the industrial establishment are as follows:

- The site that is selected shall offer good technical characteristics for carrying out construction and operation.
- The requirements and intentions of the Environmental Code and the Planning and Building Act shall be satisfied. Beyond this, local conditions and interests shall be taken into account by adaptation of investigations and repository layout.
- Voluntary grants of land use shall be striven for.

Table 10-7 provides a summary of the most important requirements and preferences with regard to utilization of land areas, consideration of competing land use interests, environmental impact and technical factors associated with the industrial establishment.

In general, it is a preference that the surface facilities can be sited within or near existing industrial areas, where both transport routes (connecting roads, rail lines, possibly harbour) and technical supply systems (electricity, telephone, water, sewerage) are already established. Another essential advantage of using

Table 10-7. Requirements and preferences with regard to industrial establishment

Factor	Requirement	Preference	Comment
Existing industrial land		Siting of the deep repository's surface facilities is simplified if they are sited on existing industrial land.	Establishment of the deep repository's surface activities on an industrial area means that supply systems (electricity, water and sewerage) and other infrastructure (roads, rail lines, harbour) are already established.
Geotechnical characteristics of site		Stable soils offer advantages; thick soil layers, mires and wetlands offer disadvantages.	Mainly local factors, which are evaluated during the site investigation.
Protected land and competing interests	Siting must be permissible under the Environmental Code	Few competing interests is an advantage.	Compliance with the law. Competing interests are evaluated from a holistic perspective.
Management of land and resources		From a land management perspective, siting on industrial land is advantageous. Forest land can also provide advantages.	Industrial land means that undeveloped areas do not have to be utilized. Forest land often, but not always, entails few competing interests.
Environmental impact during site investigations, construction and operation	Requirements are laid down in laws, conditions for the activities will be laid down in permit decisions.	Minimal environmental impact is advantageous. The preferences that can above all distinguish different siting alternatives are: - that utilization of land does not lead to blockage of natural resources or other negative consequences for current land use. - that exhaust emissions are limited. - that the landscape is not adversely affected. - that the consequences of groundwater drainage on wells, flora and fauna are small. - that a large, relatively insensitive discharge area is available for the effluent from the repository. - that a large enough area exists for temporary spoil heaps.	The site investigations shall be carried out so that environmental impacts of drilling and other investigations are small and acceptable. An Environmental Impact Statement describes the consequences for environment and health during and after construction and operation of the deep repository. This requires data from site investigations. Only then can a holistic assessment be made of environmental impact for different siting alternatives. A holistic assessment also includes consequences for other sectors, such as travel, fishing and farming, effects on property prices, societal consequences of more jobs, and psychosocial consequences of anxiety or well-being.
Land ownership		Few land owners an advantage.	Access to land is required for site investigation. The land for the surface facility must be acquired. Voluntary grants of land use are striven for.

existing industrial land is that infringement in undeveloped areas and conflicts with other land use are avoided. Besides industrial land, forest land may also be suitable, since there are often, although not always, few competing land use interests.

Till

Type of soil consisting of rock material that has been picked up, transported, reworked and deposited by the continental ice sheet. The particle size varies from large boulders to grains a few thousandths of a millimetre

Preferences regarding the ground conditions for foundation construction are the usual for industrial facilities. A thin soil cover and stable soils such as till offer technical advantages. Thick soil layers such as mires and wetlands offer disadvantages and can entail unsuitable conditions. These are, however, local factors that do not become apparent until the site investigation phase. At the present phase, the evaluations that can be made of the technical prospects are therefore linked more to transport accessibility than to construction conditions on the site.

The Environmental Code and the Planning and Building Act contain a number of provisions that must be complied with in connection with establishment of industrial facilities. Some have the character of general intentions to be taken into account, while others entail concrete restrictions for the siting possibilities. These provisions often have the character of requirements regarding which land areas may be considered for the deep repository's surface facilities, how they are to be evaluated from the infringement viewpoint and what modifications of the facilities may be needed to accommodate various protection interests.

National interest

Phenomenon of interest to the entire nation and regulated under the Environmental Code

Besides such specific restrictions, there are limitations of the siting options due to protection interests of various kind and scope. This can include everything from nature areas and cultural sites with the status of national interest, to local preservation interests and competing land use in a more general sense. SKB's aim is to avoid siting and designing the repository facilities in a way that entails a conflict with protection or preservation interests, or competing land use interests. This does not mean that sitings that cause conflicts are ruled out, since there may be advantages from other aspects that outweigh the disadvantages in an overall appraisal.

In general, the deep repository can be located and designed so that it causes little environmental impact, compared with what is usually the case for an industrial facility of equivalent size. A general and overall description of its environmental impact can be found in the final reports from the feasibility studies. A site investigation provides the material needed to make a holistic assessment of what the environmental consequences of a deep repository are on a specific site. Special emphasis must then be placed on describing the consequences of transport, of how the rock spoils are handled, and of the groundwater lowering that occurs around the repository. This material and the holistic assessment will be presented in an Environmental Impact Statement (EIS), which is an important supporting document in the application to site the deep repository on a specific site.

Evaluations of preferences must be made from a holistic perspective, where the benefits of siting the facilities on the site in question are also weighed in. This point of view is in accord with the intentions of the Environmental Code. It is not possible for SKB to specify more precisely how conflicts with various kinds of protection interests are to be evaluated in general. The particulars – what type of protected and valuable areas are affected, whether an establishment would affect them adversely and to what extent, what can be done to reduce or eliminate the impact – differ far too much from case to case. The final evaluation is done in connection with the licensing process, in other words the Government's or Environmental Court's examination under the Nuclear Activities Act and the Environmental Code of an application for a permit to build a deep repository.

SKB intends at a later stage to acquire the land areas that are needed for the facilities at ground level and for traffic connections to public transport routes. SKB also needs access to the land in the areas where the site investigations are conducted, as well as agreements with those who own the land above the planned underground facilities.

The central consideration in evaluation of the landowner question is that all grants of land use for SKB's needs can take place in consensus with the owner of the land and other concerned persons. SKB considers compulsory acquisition of land under the Expropriation Act to be an unsuitable solution. There are a number of reasons for this policy, the main one being that a positive attitude on the part of concerned landowners facilitates the implementation of the deep repository project. Consequently, SKB regards an uncomplicated ownership situation as an advantage in the overall evaluation of siting prospects.

Transportation

It is naturally a requirement that transport to and from the deep repository can be arranged in compliance with all laws and regulatory requirements. There is an extensive regulatory framework governing transportation of radioactive material that must be complied with. Otherwise, transport to the deep repository does not differ from other transport activities in society and is therefore subject to the same regulatory framework. Aside from compliance with requirements in the form of laws and regulations, all transport must be able to be carried out in a highly safe, technically rational and environmentally sound manner.

Table 10-8 provides a summary of the most important siting factors with respect to transportation. It is a preference that the deep repository can be sited so that the need for build-out of transport routes and other infrastructure is small. There are two main reasons for this: the more infrastructure needs to be built out, the greater are the infringements in undeveloped areas, and the higher the

Table 10-8. Requirements and preferences with regard to transportation

Factor	Requirement	Preference	Comment
Existing transport routes		Preference that transport to and from the repository can go via existing harbours, roads and rail lines.	Extensive construction of harbour, road and rail facilities leads to infringement in undeveloped areas and is costly.
Traffic connections	Requires permits.	Preference for short and uncomplicated connecting roads and/or railway.	See above.
Safety and accidents	Legal requirements.	Long freight shipments should be avoided. Sea transport is better than rail transport, which is in turn better than road transport.	Legal requirements must be complied with. Transportation systems for nuclear waste are designed in accordance with rigorous safety provisions. Risk for conventional accidents is assessed in an overall evaluation of different transport alternatives.
Environmental impact	Legal requirements.	Little environmental impact is desirable.	The total transport volume of goods and people to and from the repository should be as small as possible.
Accessibility		Short transport distances and few transloadings of nuclear waste, bentonite and rock spoils.	
		Quick and efficient travel for personnel is a preference.	Nearness to population centre is advantageous.

cost of the project. Other stakeholders may make different judgements, however, since build-out of infrastructure may have advantages for the community.

Ships, road vehicles and diesel-powered locomotives will give rise to air pollution. However, the increase in transport volume and associated environmental load to which various sitings give rise are not regarded as a significant siting factor. In general, the preference is nevertheless to give rise to as little transport activity as possible.

The accessibility of the site – i.e. how quickly and easily the facility can be reached – influences the operating premises from the viewpoint of safety, economics and environment and is therefore an important evaluation factor. In general, accessibility is dependent on a combination of the site's geographic location and infrastructure. When it comes to the shipments of spent nuclear fuel and bentonite clay to the deep repository, the preference of high accessibility means that short transport distances and few transloadings offer advantages. The same applies to transport of rock spoils from the repository.

Assessments of accessibility on the local scale are primarily done during the site investigation phase, as knowledge of the site grows. The personnel's daily work journeys during the operating phase account for a large portion of the total transport volume. A siting near population centres that permits quick and easy work journeys for the personnel offers advantages. Since the personnel force is relatively large and the operating phase extends over a long period of time, this is of great total importance for many people. A limited commuting need for the operating personnel is thus a preference. Transportation as a societal issue and from a public-opinion viewpoint is dealt with in section 10.4.

Labour, business community and services

The deep repository is a large and long-term industrial establishment which is in many ways dependent on the community in the locality and the region where the repository is established. The question of what are favourable conditions for an establishment can be viewed in different ways, depending on whose perspective the question is regarded from. From a regional policy perspective, for example, it can be rightly asserted that the deep repository can, technically speaking, be established virtually anywhere in the country, albeit with differences in necessary preparations, so that regional policy goals can be met.

However, SKB's primary responsibility is to see to it that the deep repository project is realized, not to take regional policy aspects into account. With feasibility as a premise, the evaluation made by SKB has to do with what resources the community can contribute to the project in the form of labour, public and private services, etc., and whether these resources meet the requirements to enable the project to be completed with high quality. When it comes to the other side of this mutual dependency, i.e. what the project can contribute to the community, SKB's role is to present the facts, but leave the evaluations to others.

Table 10-9 provides a summary of the most important siting factors with respect to the influence of community resources.

10.4 Societal aspects

For the deep repository as a societal phenomenon, it is tricky to formulate requirements and preferences or even siting factors. This is because societal standards and values are constantly changing. A fundamental requirement is that siting must be a democratic process and that public confidence in the facility must exist in the municipality.

Table 10-9. Requirements and preferences with regard to community resources

Factor	Requirement	Preference	Comment
Access to labour in the locality or region		Good access to labour in the region is advantageous.	A favourable factor for obtaining a stable and competent workforce is if personnel live in or want to move to the region.
Business community, industry, suppliers		Wide business range and large industrial sector are advantageous.	Permits a large share of local procurement and gives nearness to suppliers, providing better efficiency in all stages.
		Experience of nuclear and/or rock engineering activities is advantageous.	Provides greater opportunities to recruit personnel locally.
Public services, education		Good access to public services and education is advantageous.	Provides greater opportunities to recruit personnel locally and get personnel to move to the region.

Business range

Number of business sectors represented in the region

A controversial establishment

Nuclear waste management in general and siting of a deep repository in particular is, and has long been, a controversial issue in the public debate. The discussion spans a broad field, ranging from the nuclear waste in an energy and environmental policy context to very local issues regarding what a deep repository may mean to a specific locality or for individual nearby residents and landowners.

The factors that are important for achieving the societal and scientific support that is needed in order for a deep repository project to be implemented with good results are illustrated in Figure 10-1 and discussed below. Table 10-10 summarizes the discussion.

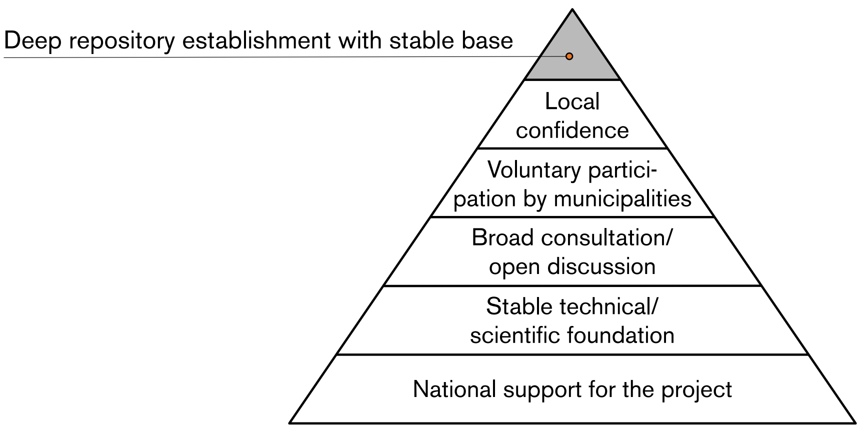


Figure 10-1. *A successful establishment of the deep repository needs to rest on a stable scientific and societal foundation.*

Table 10-10. Requirements and preferences with regard to societal aspects

Factor	Requirement	Preference	Comment
National support	The Government accepts SKB's programme.	Clear statements from political leaders.	Requirement satisfied so far. The outspoken national support has been strengthened in recent years but could be further improved.
Stable technical and scientific foundation	The safety authorities have no significant objections to the thrust of SKB's programme.	Outspoken broad scientific support for the programme.	Requirement satisfied so far. There is broad scientific support for the programme. This is evident from the comments of the reviewing bodies on SKB's RD&D programmes and from the scientific community's reactions to SKB's technical reports in scientific forums.
Broad consultation and open discussion	Formal requirements are laid down in the Environmental Code, etc.	Broad participation by all parties in consultation procedure. Open and constructive discussions with all concerned.	A good foundation has been laid during the feasibility study phase. The municipalities and county administrative boards have built up competence and commitment.
Voluntary participation by concerned municipalities	Municipal council says yes to a siting application. The municipalities do not oppose participation in the siting work.	Broad outspoken support in municipal council and among municipal inhabitants for participation in the siting process.	Requirement satisfied in all six feasibility study municipalities so far. Good prospects of gaining support for continued participation.
Local confidence	The project must be feasible from a public opinion point of view, which requires broad confidence in the concerned localities.	Opportunity for broad and constructive discussion. Local confidence in SKB and the nuclear waste programme right from the start.	The local discussion climate that is established at an early stage has been found to be of great importance later on as well. Local confidence can vary between the sites being considered.
		Alternatives that do not require overland transport are advantageous.	The public's attitude towards overland transport is an important and enduring uncertainty factor.

National support

The requirements that must be met for SKB to proceed with the work are that the division of responsibilities that has applied so far remains valid, and that the Government approves the thrust of the programme which SKB periodically submits in accordance with the requirement in the Nuclear Activities Act.

In SKB's judgement, these requirements are satisfied as long as a broad political majority exists for continued support for the statutory division of responsibilities that applies in the nuclear waste field. There are those that say that the responsibilities should be divided differently, and that it is wrong to give the nuclear power industry so much responsibility and thereby influence in the nuclear waste issue, but these opinions have not found wide acceptance.

The preference that can be formulated with regard to the national support factor is that such support be clearly and distinctly expressed at the national political level, above all by the Riksdag and the Government. Such support has previously been lacking, in SKB's opinion. When the feasibility study work began in Storuman and Malå, too much political responsibility ended up at the local level. Some improvement has taken place in this respect in recent years. Now there is a regulatory framework for the siting programme, along with statements of support from political leaders for the purpose and structure of the nuclear waste programme. All in all, SKB judges that the national support needed to proceed with the siting work in the planned manner exists today.

A stable technical/scientific foundation

A stable technical/scientific foundation comprises the entire basis of a credible and feasible project. Here it must be a question of scientific and technical judgements rendered upon independent critical examination of the research results gradually accumulated by SKB. The assessment thus lies on the scientific plane – "you can't vote about technology and safety" – but an interesting question from the societal viewpoint is whether decision-makers, concerned parties and the general public obtain a fair and comprehensible picture of the scientific background and its assessment. This is, after all, necessary if society is to make well-founded decisions. SKB believes that there are good prospects that this will be possible.

Few questions in society will be subjected to such thorough scrutiny and analysis as the siting of the deep repository. There is naturally also a risk of intentional or unintentional distortion of the facts for the purposes of positive or negative propaganda. In this context, the radiation protection, safety and environmental authorities have a responsibility to explain clearly their judgements of the risks that exist and the level of safety that is possible to achieve. It is these authorities which must make the final holistic environment and safety assessments on behalf of society.

One requirement that must be satisfied to move ahead with the work is that the regulatory authorities, especially the Swedish Nuclear Power Inspectorate, must not have any significant objections to the structure of the work. As long as the work of gathering background material is in progress, it is enough for the authorities to provide assurance that the thrust and quality level of the work is satisfactory. The authorities shall then stand free to judge the final body of material. The review that was conducted of SKB's most recent research programme shows that there is support on the part of the authorities and the scientific community for the technical/scientific thrust of the programme.

Technical-scientific factors play a decisive role for the final choice of site. The knowledge that exists after a number of feasibility studies is, however, not sufficient to decide conclusively whether the sites selected for site investigations will satisfy the requirements. This cannot be decided until the detailed knowledge obtained from these investigations has been evaluated. SKB would like to emphasize in this context that siting also needs to be based on other assessments.

Broad consultation and open discussion

An important aspect for obtaining support and confidence for such a project as the deep repository is the credibility of the actual working method. Is the project conducted in an open and honest fashion? Are the results reported so that they are accessible to everyone? Are they reviewed by independent bodies? Are criticisms and objections taken seriously? Are questions from the public answered? Are the activities open to inspection?

During the feasibility study phase, a good framework has been built for public insight and for projecting a credible image of the working method. An important part of this effort has been that the municipalities that have participated in the feasibility study phase have managed to generate commitment and build up local competence. SKB finds it particularly encouraging that they have often managed to enlist the active participation of virtually all political parties and widely divergent interest groups. If the forms for and breadth of the consultation procedure can continue to be developed, this will greatly contribute to the quality and relevancy of the material to be gathered by SKB. In this respect, we view the local and municipal work as an asset in the whole process.

Voluntary participation on the part of concerned municipalities

A fundamental point of departure for SKB's siting work right from the start in the early 1990s has been the principle to only work in municipalities that are not opposed to participating in the siting work. This principle has the following basis:

- The main rule of the Environmental Code is that a concerned municipality has a veto. With regard to siting of nuclear installations, however, the Government may grant a permit despite the fact that the municipal council has said no, the so-called "veto valve". SKB's view is that a deep repository can only be sited where both the safety requirements are satisfied and the municipality is positive to the siting.
- International experience shows that successful sitings of controversial activities are almost always based on voluntary participation.
- SKB believes that such a long-term activity and establishment as the deep repository project cannot be satisfactorily realized against the will of the municipality.

A requirement for SKB to proceed in a municipality is therefore that the municipality is not opposed to this. By not later than the time the application is submitted, the concerned municipality must clearly give its support, and it is a preference that this be done for each new step in the process, for example prior to the start of site investigations.

An investment of the size represented by the deep repository affects not only the directly concerned municipality, but also the region. The support of neighbouring municipalities and county administrative boards is a positive factor for the municipalities on whom the decision rests.

Local confidence

Voluntary participation on the part of the municipality comes to formal expression in the position taken by the members of the municipal council, who are elected by the citizens in the municipality and thereby represent them in the democratic system we have in Sweden. The position taken by the municipal councillors will rest on their judgement of a complex reality comprising facts, values and different currents of opinion in the municipality.

Good confidence in the deep repository among those directly concerned, above all nearby residents and landowners, is particularly imperative for SKB. The way these groups perceive the repository may vary widely both in time and depending on how different individuals are affected or where there political sympathies lie. One of the decisive factors is how SKB behaves and how the project concretely affects the near environment in different ways. It is an advantage and facilitates matters greatly if there are signs already during the feasibility study phase that it is possible to have a good discussion locally in the areas that are of potential interest.

Via goods transports to and from the facilities, the establishment of the deep repository can affect other municipalities and localities than the one where the facilities are located. Experience from both Sweden and other countries shows that shipments of radioactive material can be controversial. In Sweden, shipments of spent nuclear fuel and other radioactive waste by sea have long been an accepted reality. There are no overland shipments on public transport routes, making it difficult to judge how they would be perceived by the general public and nearby residents. Not until the issue becomes concrete in a locality can local attitudes among the public and nearby residents be fully ascertained. SKB's judgement is that considerable uncertainties exist as to whether shipments of nuclear fuel on public transport routes are acceptable to public opinion or not. This is particularly the case with shipments through urban areas and is probably true to a greater extent of road shipments than of rail shipments.

There are no patent solutions for the best way to proceed when there is well-established local resistance to an establishment, even though the general attitude in a municipality is overwhelmingly positive. This is a democratic dilemma which must be handled at the political level. SKB's basic policy is that local opinion is of great importance, but that time must be allowed for thorough discussions and modification of the design of the project in response to justified local interests before local opinion is given a decisive influence on whether investigations and siting can take place in an area.

11 Siting alternatives from feasibility studies

This chapter presents the preliminary siting alternatives for the deep repository that have emerged from the feasibility studies of the six municipalities included in the selection pool, namely Älvkarleby, Tierp, Östhammar, Nyköping, Oskarshamn and Hultsfred. The descriptions and evaluations that are presented are general and are derived from the results and conclusions presented in the different feasibility studies. For references and more detailed accounts of the different alternatives, as well as how they have been identified, the reader is referred to the feasibility studies and their final reports.

11.1 Feasibility studies

The conclusion of the study site investigations (see Chapter 9) conducted by SKB during the 1980s, combined with general geological knowledge, was that good geological prospects for a deep repository probably existed at many sites in the country. This conclusion has since received support in the county-specific geological siting studies performed by SGU. Another lesson learned from the study site investigations was that local confidence in the deep repository project is necessary to be able to conduct the investigations needed to ascertain whether a site is suitable or not.

When the siting work started in the early 1990s, it was therefore focused on making a more detailed assessment of the prospects of a deep repository establishment in municipalities that were generally judged to have good geological prospects and that were not opposed to such studies. The reason why municipalities were chosen as a suitable point of departure was that they are the formal administrative unit that represents the local populace. At the same time they are as a rule sufficiently large (typically on the order of 1,000 square kilometres) to provide good opportunities in a siting process for finding an area approximately two square kilometres in size with suitable bedrock for the deep repository.

SKB has carried out feasibility studies of eight municipalities (see Chapters 8 and 9) /11-1 to 11-8/. There have been other municipalities that have been interested, but where SKB has advised against further studies on geological grounds, as well as municipalities that have considered the question but decided to refrain from participating in the siting work. The eight studied municipalities were initially judged to have geological, industrial and societal prospects that warranted a feasibility study. All have also met the requirement of not being opposed to a feasibility study.

Feasibility studies have been carried out in eight municipalities. An additional ten or so municipalities have been interested but have decided to refrain from participation.

The first two feasibility studies were conducted in the municipalities of Storuman and Malå in Västerbotten County in northern Sweden. In 1992, Storuman Municipality invited SKB to provide information on the prospects of a feasibility study in the municipality. SKB then made an internal assessment showing that there were good geological, technical and environmental prospects for a feasibility study. In the spring of 1993, Malå Municipality similarly received information from SKB, after which SKB made an internal assessment of the prospects in Malå Municipality. This, and continued contacts between SKB and the two municipalities, led to the execution of feasibility studies, concluding with final reports in 1995 and 1996, respectively. In keeping with the results of local referendums, both Storuman and Malå municipalities have since declined further participation in the siting process. Therefore, even though the feasibility studies revealed good prospects, no siting alternatives from these municipalities are included in the selection pool.

In southern Sweden, a general siting study was performed of five municipalities with nuclear activities (see Chapter 9). The reason was that these municipalities had access to nuclear competence and a suitable infrastructure, which in turn warranted a general siting study of the geological prospects there. The result was that four of the five municipalities were judged to have suitable bedrock. Three of the municipalities – Östhammar (1995), Nyköping (1995) and Oskarshamn (1996) – agreed to allow feasibility studies to be conducted.

In conjunction with the feasibility study in Östhammar, SKB also contacted the neighbouring municipality of Tierp. The reason was that SKB wanted to investigate the prospects around Forsmark and include the bedrock in Tierp Municipality, and that the general siting study of Uppsala County indicated suitable conditions in several areas in Tierp Municipality. Tierp Municipality decided to participate in a feasibility study in 1998. Finally, a feasibility study was undertaken in Älvkarleby Municipality in 1999. The reasons were that the general siting study indicated suitable conditions in the municipality, and that shipments to a deep repository in the municipality of Tierp would probably involve the municipality of Älvkarleby, via the harbour in Skutskär and the rail line through the municipality.

The feasibility studies in Northern Uppland have resulted in the following three siting alternatives, see Figure 11-1.

- Forsmark, municipality of Östhammar,
- Hargshamn, municipality of Östhammar,
- Tierp north/Skutskär, municipalities of Tierp and Älvkarleby.

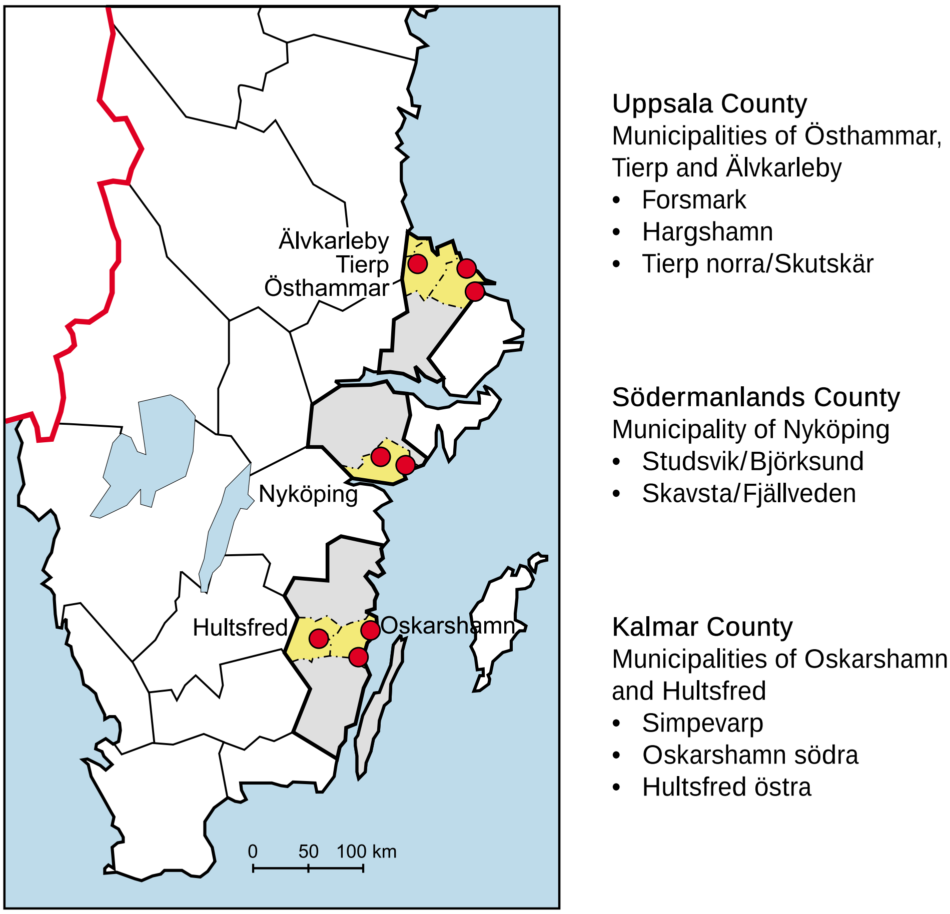


Figure 11-1. *The feasibility studies have identified eight siting alternatives for the deep repository. They comprise the selection pool for the choice of sites for site investigations.*

The feasibility study in Nyköping Municipality led to the presentation of Studsvik/Björksund as a siting alternative in the preliminary final report from the feasibility study. Comments in conjunction with the circulation of the preliminary final report for review have led to the identification of an inland alternative, Skavsta/Fjällveden, as well. However, the latter alternative has not been discussed within the municipality in the same way as the Studsvik alternative. Today the following siting alternatives exist:

- Studsvik/Björksund, municipality of Nyköping
- Skavsta/Fjällveden, municipality of Nyköping

Oskarshamn Municipality contains large areas with mutually similar, potentially favourable bedrock. It has not been possible to rank these areas with respect to the bedrock based on existing data. Instead, the siting alternatives have been chosen in areas that are favourable from an infrastructural viewpoint in particular.

The general siting study of Kalmar County revealed potentially favourable conditions west and south of Oskarshamn Municipality. This was reported at a meeting with all neighbouring municipalities to Oskarshamn at the County Administrative Board in Kalmar, whereby SKB invited the municipalities deemed to have suitable bedrock to participate in a feasibility study. Of the municipalities that were asked, Hultsfred was the one that showed an interest. This led to the execution of a feasibility study in the municipality, with the result that a siting alternative was identified.

The feasibility studies of Oskarshamn and Hultsfred have thereby resulted in the following siting alternatives:

- Simpevarp, municipality of Oskarshamn
- Oskarshamn south, municipality of Oskarshamn
- Hultsfred east, municipality of Hultsfred

Altogether, the feasibility studies that have been conducted have thus resulted in eight siting alternatives, which now comprise the selection pool for the site investigation phase.

The scope of each feasibility study is described in a final report or preliminary final report. In general, the investigation work has been divided into the following disciplines: safety, technology, land and environment, and society. A prerequisite has been that the studies shall primarily compile and analyze existing material. In addition, general geological field checks have been made of interesting areas. Test drilling has not been included, however.

11.2 Application of siting factors

The feasibility studies have been planned and executed with the guidance of the premises and siting factors that were laid down in connection with the Government decision that followed upon SKB's supplement to RD&D-Programme 92, see Chapter 8. In order to obtain data as a basis for assessing the siting prospects in different respects, broad compilations and analyses have been made of existing geoscientific information, as well as available data on infrastructure, land use, and environmental and societal conditions.

In all feasibility studies, the geoscientific investigations have led to the dismissal of parts of the municipality from further studies, but also to the identification of areas judged to be of interest. Based on these results, and information on the technical and environmental prospects for establishment, transport options etc., integrated evaluations have been made. The next step has been to perform geological field checks and in some cases supplementary studies of areas and alternatives that have been found to be particularly interesting. In many cases, but not always, the field checks have verified the previous positive assessment.

In keeping with the method described above, the feasibility studies have included the following three steps:

1. Areas that exhibit potentially negative geological conditions are excluded.
2. Particularly interesting areas are selected for field checks and supplementary studies.
3. Evaluation of siting alternatives.

Step 1 - Exclusion of areas with potentially negative geological conditions

The following factors have been taken into consideration:

- Rock types that are of interest for mineral extraction or other utilization.
- Highly heterogeneous or difficult-to-interpret bedrock.
- Known deformation zones or neotectonic (geologically recent) faults.
- Pronounced groundwater discharge areas.
- Indications of groundwater chemistry that is abnormal for Swedish bedrock.

Areas that exhibit such conditions have been avoided.

Step 2 - Choice of areas for field checks

After areas that exhibit potentially unsuitable geological conditions have been dismissed from further studies, a number of areas usually remain. One or more areas that have been judged to be interesting siting alternatives due to favourable technical and environmental prospects have been selected for field checks and supplementary studies.

Step 3 - Evaluation of siting alternatives

After field checks and other studies, an integrated evaluation has been made of which alternatives have particularly good prospects of satisfying requirements and preferences, both from the safety viewpoint and with regard to technology, land and environment, and societal aspects. The evaluation also includes an assessment of the possibilities of determining whether this is the case by means of further investigations.

In this evaluation, the following conditions have been deemed desirable:

- An ordinary rock type of no interest for other utilization of natural resources. This reduces the risk that the area will be chosen for other use in the future.
- A large area with few major fracture zones. This provides extra flexibility in future investigations and increases the possibilities of being able to build a sufficiently large repository in good rock.
- A high proportion of exposed rock and/or thin soil cover, simple and homogeneous bedrock conditions, and a regular system of fractures and fracture zones. This provides good opportunities for obtaining a good understanding at an early stage of bedrock conditions of importance for the prospects of safety and rock construction.
- Access to the necessary infrastructure and good transport options in the form of harbours, railways or roads. Limited need to make use of land for new roads or railways.
- Few competing land use and environmental interests. This provides wide options for modifying the facilities to comply with the environmental requirements.
- Local positive interest.

Table 11-1 summarizes factors that have been taken into consideration in the feasibility studies and that concern conditions of importance for long-term safety as well as construction and operation of the deep repository's rock facilities. The table also describes how these factors tie in with the requirements and preferences regarding the rock discussed in Chapter 10.

Table 11-1. Geoscientific factors that are studied in feasibility studies, based on requirements and preferences formulated for the rock (see Chapter 10)

Factor	Relevant requirements or preferences	How requirements and preferences have been taken into account in feasibility studies
Rock types, development interests and homogeneity of bedrock	The rock may not have ore potential.	Further studies and investigations only of areas not judged to have any potential for occurrence of ore or valuable industrial minerals.
	It is an advantage if it is a common and homogeneous rock type.	Areas with highly heterogeneous or difficult-to-interpret bedrock are avoided. Areas deemed to be homogeneous and to consist of ordinary rocks are advantageous.
	Suitable thermal properties.	An ordinary rock type satisfies the preference of suitable thermal properties.
	Low radon potential.	Areas with high radon potential are avoided.
Deformation zones and stability	Regional plastic shear zones and large fracture zones may not be present in the deposition area.	Areas that are chosen for further studies shall be such that the repository can be expected with good margin between known plastic shear to fit zones and large fracture zones. This means that a large area with few major fracture zones is advantageous. Known neotectonic faults are avoided.
	It is good if the frequency of fractures and local minor fracture zones is low.	Areas where the fracture frequency is low in outcrops are deemed to be advantageous.
Soil cover	A high proportion of exposed rock and otherwise thin soil cover is a preference.	Areas with a high proportion of exposed rock and/or thin soil cover are favourable. Areas with a low proportion of exposed rock are also considered if the geological and geophysical conditions are such that they are easy to interpret.
Groundwater flow	The hydraulic gradient at repository level should be less than 1%.	Areas with a high topographical gradient (1%) on a regional scale are avoided.
		Pronounced discharge areas are avoided.
Groundwater chemistry	Groundwater at repository level must have a salinity TDS<100 g/l and be free from dissolved oxygen. A normal groundwater chemistry is desirable.	Areas with indications of a groundwater chemistry that is abnormal for Swedish bedrock are avoided.

Ore-potential bedrock
Bedrock with such geological characteristics that it could be of interest for ore prospecting

Thermal properties
Properties that determine how heat is conducted away from the repository and how the rock expands when it gets hotter

Plastic shear zone
Deformation zone formed as a result of plastic deformation, i.e. under high pressure and high temperature at great depth

Neotectonic faults
Faults between two rock blocks that have occurred during or after the most recent ice age

Hydraulic gradient
The change in the hydraulic head per unit distance, i.e. the slope of the groundwater table

TDS
Total Dissolved Solids (a measure of total salinity)

11.3 Northern Uppland - Östhammar, Tierp and Älvkarleby

Figure 11-2 shows a key map of Northern Uppland with the three municipalities where feasibility studies have been done: Östhammar, Tierp and Älvkarleby. General information on these municipalities is summarized on the next page.

11.3.1 General prospects for a repository in the region

Good prospects exist in Northern Uppland for establishing and operating a deep repository and other facilities in the waste management system in a way that satisfies all requirements on environmental consideration and technical function. The region has an extensive infrastructure and good societal resources. Most of the competence required by the deep repository project is available, including know-how in the heavy engineering industry, the transport sector, the building sector and nuclear activities. Nearness to universities and colleges in the region also contributes to a good recruitment base.

In terms of transportation infrastructure there is the Ostkustbanan (East Coast Railway) and the E4 highway, which make it possible to reach Uppsala, Arlanda and Stockholm within an hour or so. There are several harbours that can be used for shipments to the repository. All in all, SKB deems the region's general prospects for a deep repository establishment to be very good.

Figure 11-2. Municipalities of Östhammar, Tierp, and Älvkarleby.

Östhammar Municipality

The municipality of Östhammar has historically rested on three pillars: fishing/shipping, iron/steel and agriculture. Today it is dominated by two corporations: Sandvik Coromant AB with some 1,500 employees, and Forsmarks kraftgrupp AB with some 800 employees. Roughly 1,500 persons work in the agricultural sector.

There are several Wallonian ironworks of historical interest in the municipality. Together with the nuclear power plant and SFR in Forsmark, the ironworks are the most popular tourist destinations. The coastal and archipelago areas are also important tourist attractions.

Location
Coastal municipality in Uppsala County. Borders in the west on Tierp, in the southeast on Norrtälje and in the south on Uppsala.

Land area	Inhabitants
2,790 km^2	Approx. 21,600

Towns
Östhammar pop. 4,700, Gimo pop. 2,700, Alunda pop. 2,300, Österbybruk pop. 2,200, Öregrund pop. 1,600.

Transportation
A railway for goods transport passes through the southern part of the municipality. Highway 76 passes through the northern part of the municipality and county road 292 through the southern part. Harbour for heavy goods traffic in Hargshamn. Arlanda Airport is situated approximately 1.5 hours from Östhammar.

Land
Approximately 71% forest land, 14% arable land and pastureland, 15% built-up and other land.

Political leadership
The seats in the municipal council are distributed as follows: Social Democrats 22, Left Party 4, Moderates 9, Christian Democrats 2, Centre Party 8, Liberal Party 2, Green Party 2.

Feasibility study decision
June 1995 - 36 yes, 12 no.

Nuclear power-associated activities
- Forsmark NPP with three reactors, the oldest in operation since 1980.
- SFR (Final Repository for Radioactive Operational Waste) in operation since 1988.

Tierp Municipality

Tierp is situated in a district with a lot of history. Today the manufacturing industry dominates the region's economy. Construction, agriculture and forestry are other important economic sectors. The largest private employers are Atlas Copco Tools AB with some 370 employees, EraSteel Kloster AB with around 250 employees, and Karlit AB with about 185 employees.

Geographically, the municipality is dominated by the Dalälven River and nearness to the Baltic Sea. It contains Central Sweden's largest wetland area, Florarna. Örbyhus Castle and well-preserved mill communities are also located in the municipality.

Location
Coastal municipality in Uppsala County. Borders on Älvkarleby and Gävle in the northwest, Heby in the southwest, Uppsala in the south and Östhammar in the east.

Land area	Inhabitants
1,543 km^2	Approx. 19,900

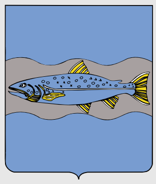
Towns
Tierp pop. 5,200, Örbyhus pop. 1,800, Söderfors pop. 1,700, Karlholmsbruk pop. 1,300.

Transportation
Ostkustbanan (The East Coast Rail-way) (Uppsala-Gävle) passes through the municipality. Upptåget is a train that runs from Tierp to Uppsala in just under 40 minutes. The E4 highway passes through the western part of the municipality. After many years of discussion, a rerouting of E4 nearer the town of Tierp has recently been approved. There are no harbours for heavy goods traffic, but further up the coast are the harbours in Skutskär and Gävle, and in the east Hargshamn. Arlanda Airport is situated approximately 1 hour from Tierp.

Land
Approximately 70% forest land, 15% arable land and pastureland, 15% built-up and other land.

Political leadership
The seats in the municipal council are distributed as follows: Social Democrats 24, Left Party 4, Moderates 6, Christian Democrats 3, Centre Party 7, Liberal Party 2, Green Party 2, Stop E4 West Culture Party 1.

Feasibility study decision
June 1998 - unanimous.



Älvkarleby Municipality

Älvkarleby Municipality has an industrial tradition dating back to the 17th century, when two ironworks were built. The district still bears a clear industrial stamp. The manufacturing industry accounts for nearly one-third of the jobs. Timber and hydropower are the basic resources, and the largest private employers are Stora Enso AB with some 500 employees and Vattenfall Utveckling AB with some 135 employees.

The Dalälven River flows through the whole municipality from south to north, discharging into the Bothnian Sea. There are ample opportunities for an active outdoor life and cultural activities. The foremost attraction for both municipal inhabitants and tourists is fishing.

Location
Coastal municipality in the far north of Uppsala County. Borders in the south and east on Tierp and in the west on Gävle.

Land area	Inhabitants
208 km^2	Approx. 8,990

Towns
Skutskär pop. 5,700, Älvkarleby pop. 1,500, Gårdskär pop. 400, Marma pop. 300.

Transportation
Both Ostkustbanan (The East Coast Railway) (Uppsala-Gävle) and the E4 motorway pass through the municipality in a north-south direction. Highway 76 runs through the central and northern parts of the municipality, while county road 291 connects to E4. There is a harbour for heavy goods traffic at the Skutskär Works. There is an airport with scheduled service in Gävle/Sandviken. Arlanda Airport is situated about two hours from Skutskär.

Land
Approximately 70% forest land, 3% arable land and pastureland, 27% built-up and other land.

Political leadership
The seats in the municipal council are distributed as follows: Social Democrats 15, Left Party 3, Moderates 3, Christian Democrats 1, Centre Party 1, Liberal Party 2, Green Party 1, Democratic List 5.

Feasibility study decision
June 1999 - 30 yes, 1 no.

The Forsmark NPP in the municipality of Östhammar has contributed to the confidence that exists in nuclear activities in the region. The Final Repository for Radioactive Operational Waste (SFR), which has been in operation for more than ten years, is situated at Forsmark. Spent nuclear fuel and other nuclear waste has been satisfactorily transported by M/S Sigyn for more than fifteen years.

11.3.2 Geological prospects for a repository in the region

Plutonic rock
Rock formed at great depth in the earth's crust by magma (molten rock) that has been forced up and solidified

Supracrustal rock
Rock that has formed near the earth's surface due to sedimentary or volcanic processes

Volcanite
Rock formed by volcanic processes such as expulsion at the earth's surface of lava, fragments, ash, gases, etc.

Orogeny
Process of mountain formation

Plastic deformation
Deformation under high pressure and temperature, at which the bedrock behaves like a viscous mass

Foliation
Planar arrangement of mineral grains

Northern Uppland exhibits wide variation in bedrock conditions. Most common are plutonic rocks, mainly gneissic granites (metagranites) and massifs of younger granite, but greenstones and supracrustal rocks such as volcanites and sedimentary gneisses also occur. All rocks that are around 1,850 million years or older have been more or less affected by the period of orogeny (formation of mountains) that is usually called the Svecokarelian orogeny. The bedrock was then subjected to varying degrees of deformation and metamorphosis, sometimes so extensive that it led to melting, sometimes with relatively little effect. When this deformation phase had culminated, molten rock (magma) intruded into the bedrock and formed younger granites, in some cases in the form of large homogeneous massifs. Finally, hypabyssal rocks, such as dolerite and aplite, have penetrated into fractures or otherwise infused the bedrock.

During the latter part of the above-mentioned deformation phase, probably around 1,850–1,750 million years ago, large-scale plastic shear zones formed. An example is the Singö shear zone along the Uppland coast. Within this zone are wide bands where the bedrock is foliated and heterogeneous. Between the bands are relatively unaffected formations, called tectonic lenses. At a later stage the bedrock has been affected by brittle deformation, whereby several older plastic shear zones have been reactivated and new fractures, fracture zones and faults have been formed.

As a result of this geological history, the bedrock of Northern Uppland is characterized by:

- Dominance of gneissic granites in the entire region.
- Massifs of younger granite, especially in the western part.
- Smaller areas with supracrustal rocks, mainly in the eastern part.
- Ore potential, mainly associated with volcanic supracrustal rocks.
- High degree of metamorphosis and heterogeneity, especially in the northern part.
- Regional plastic shear zones, especially in the eastern part.
- Normal occurrence of fracture zones throughout the region.

The proportion of exposed rock varies, from relatively high in the coastal area to low in the northern and western parts of the region. There are virtually no modern geological maps for the latter parts.

All in all, due to these geological conditions, large parts of the region have been deemed to be of no interest. However, in the municipalities of Östhammar and Tierp there are several areas that remain after areas with unsuitable conditions have been excluded, see Figure 11-3. Characteristics shared by these areas are that they consist of older or younger granitic massifs with few indications of fracture zones, that they are not affected by regional plastic shear zones or bedrock with ore potential, and that the geological environment is such that the reliability of the assessment is deemed to be good.

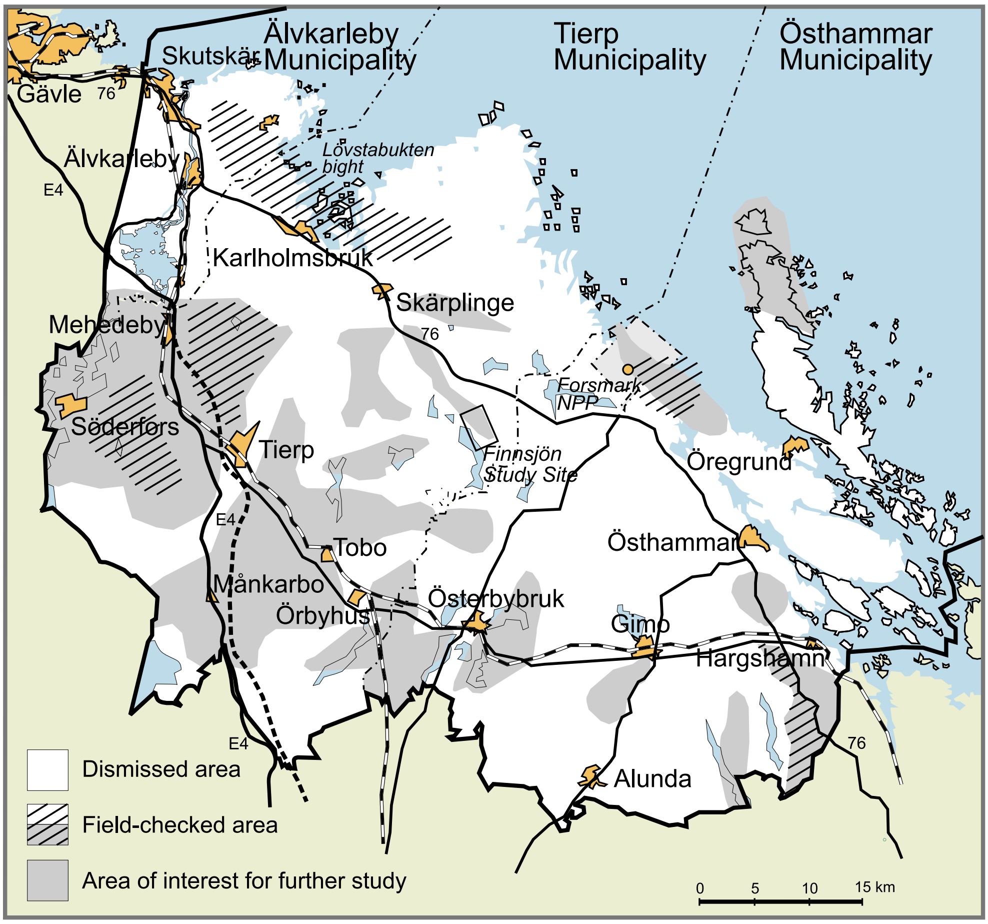


Figure 11-3. *Feasibility studies' assessment of the bedrock in the municipalities of Östhammar, Tierp and Älvkarleby.*

11.3.3 Siting alternatives

In accordance with the described methodology for the feasibility studies, areas of interest in the three municipalities in Northern Uppland were selected for geological field checks. The choices were based on geological assessments, with results as shown in Figure 11-3, plus studies of technical, environmental and societal prospects.

Municipality of Östhammar

Two areas in the municipality of Östhammar were selected for field checks: one adjacent to Forsmark and the other west of Hargshamn. These areas were deemed to be of preliminary interest for further geological studies. Furthermore, they are located near the harbours of Forsmark and Hargshamn, respectively, both with capacity for M/S Sigyn and her successors. In the case of Forsmark, nearness to the nuclear power plant and SFR were also accorded great importance, in view of the advantages a co-siting would afford in the form of access to existing industrial land and infrastructure, plus possibilities for operational coordination. Hargshamn was also judged to have good infrastructural prospects.

The field checks verified the previous assessment of the two areas as being potentially suitable for a deep repository. Forsmark and Hargshamn thereby remained as interesting alternatives for site investigations, see Figure 11-4. The feasibility study prioritized the Forsmark alternative, mainly for reasons of coordination.

Siting alternatives in Northern Uppland

- Forsmark
- Hargshamn
- Tierp north/Skutskär

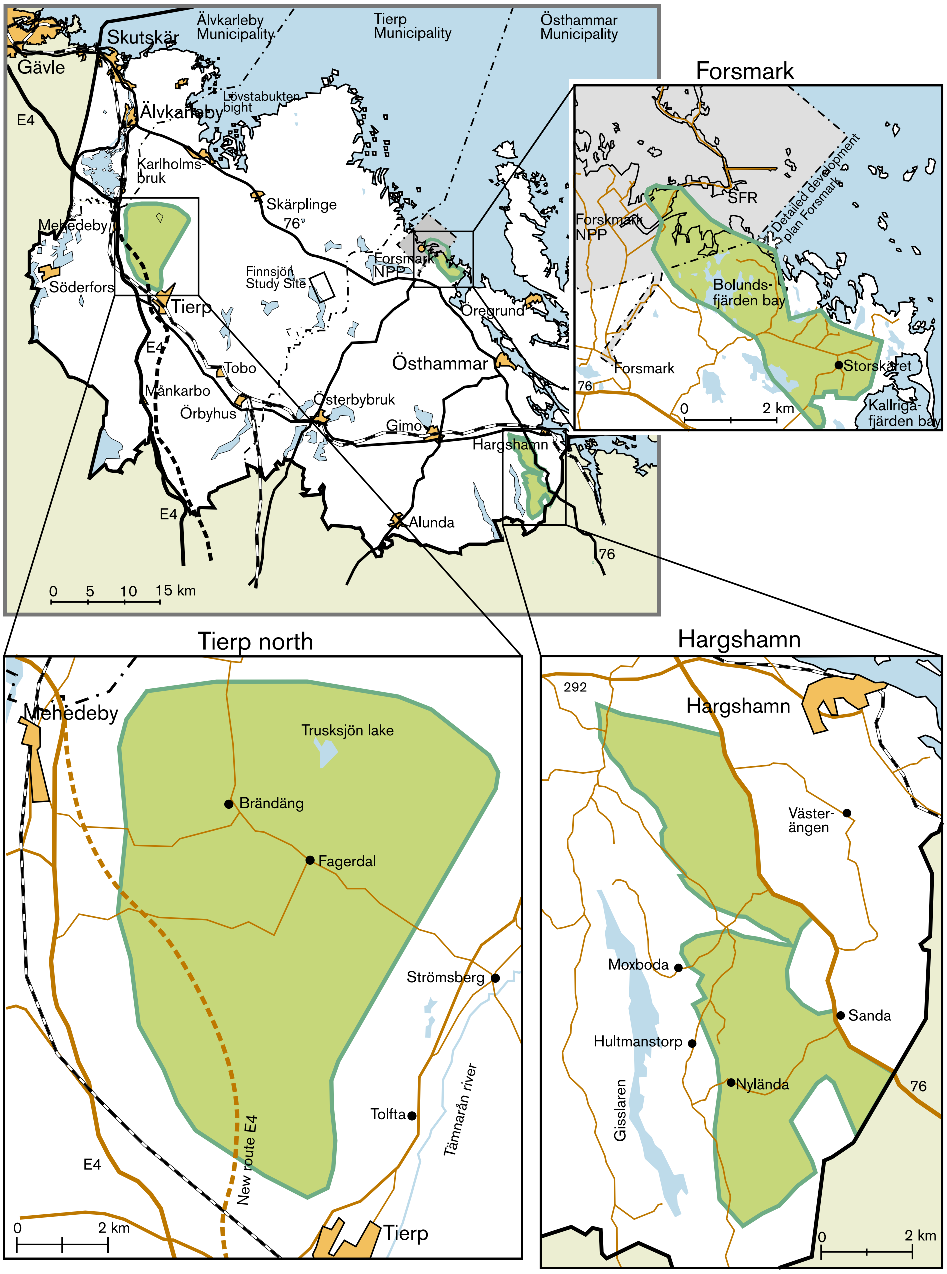


Figure 11-4. *The three areas in Northern Uppland that were judged by the feasibility studies to be suitable for site investigations.*

Municipality of Tierp

The feasibility study in the municipality of Tierp led to the judgement of two granite areas as being of interest for further studies, although with reservations for inadequate geological maps and a low proportion of exposed rock. Both areas are situated within granite massifs that are younger than the dominant gneissic granites in the region. They represent a geological setting that is different from the alternatives in the municipality of Östhammar.

The one area is situated in the southwestern portion of the municipality of Tierp and comprises a large portion of the large granite massif usually known as the Hedesunda granite (the town of Hedesunda is located some 10 km to the west, in the municipality of Sandviken). One reason the area was judged to be an interesting siting alternative is because the East Coast Railway passes through it. This would permit transport from a suitable harbour, preferably Skutskär in the municipality of Älvkarleby, without extensive build-out of transport routes. After geological field checks /11-9/ and other considerations, parts of the area remained of interest for a site investigation, see Figure 11-4.

The other area that was selected for field checks was a granite massif at Lövstabukten bight in the municipality's coastal region. Here, however, field checks found serious drawbacks as regards suitability for further studies. The area is therefore not a candidate for site investigations.

This left one siting alternative of interest for further studies in the municipality of Tierp, see Figure 11-4.

Municipality of Älvkarleby

SKB's conclusion is that there is no area in the municipality of Älvkarleby that can be recommended from a geological viewpoint for site investigations. The field checks that were done within an area that was preliminarily judged to be of interest /11-9/ revealed that the bedrock is more heterogeneous than had previously been known. This, together with the fact that there are few outcrops and otherwise poor conditions for mapping of the bedrock, makes geological assessments difficult, particularly of conditions at great depth. Test drilling could compensate to some extent for these disadvantages, but the geological environment is so heterogeneous that significant uncertainties regarding the bedrock between the boreholes would nevertheless probably remain. The conclusion is that an unreasonable number of boreholes would presumably be required before the entire rock volume occupied by a deep repository could be considered to be so well investigated that a reliable assessment of long-term safety could be made.

Site investigations in the above-mentioned area in the municipality of Tierp also require the cooperation of the municipality of Älvkarleby, since the industrial port at Skutskär is a priority alternative as a harbour for transport to and from the deep repository.

11.3.4 Forsmark

An approximately 10 square kilometre area between the Forsmark NPP and Kallrigafjärden bay is judged to be potentially favourable for a deep repository, see Figure 11-4. If the repository is sited in this area, a receiving harbour and industrial facilities can be built on the existing industrial area in Forsmark.

Figure 11-5 shows a schematic system design for this siting alternative. The existing harbour is used to receive waste for both SFR and the deep repository. Since the capacity of the harbour only permits coastal tonnage, the backfill material (bentonite) can be carried on larger ships to Hargshamn and transshipped there, either for further sea transport to Forsmark or to a truck for road transport directly from Hargshamn. Another possibility is to modify the harbour and the channel in Forsmark to accommodate larger vessels. The deep repository's surface facility is built adjacent to SFR. The repository in the area of geological interest is then reached via an approximately 4–6 kilometre long sloping tunnel.

Bedrock

The area in question between the Forsmark NPP and Kallrigafjärden bay consists of a red metagranite, popularly called gneissic granite. The gneissic granite is situated in a tectonic lens surrounded by regional fracture zones and plastic shear zones. The fracture zone east of the area is named the Singö Fault. Four tunnels intersect this fracture zone: two are cooling water tunnels from the NPP and two are tunnels to SFR.

There are topographical and other indications of an equivalent fracture zone west of the area of interest as well. The distance between these two regional zones is approximately two kilometres. The bedrock in the tectonic lens between the zones is relatively unaffected by plastic deformation. The soil cover is judged to be relatively thin (typically a metre or so) and outcrops are scattered through-

Tectonic lens

Area, enclosed in a plastic deformation zone, which is unaffected or much less affected by plastic deformation than the rest of the deformation zone

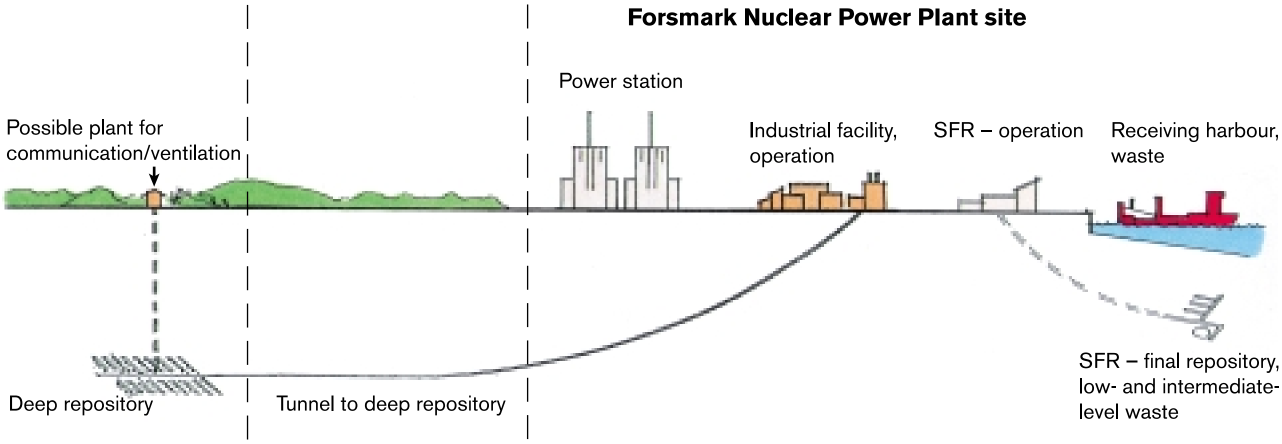


Figure 11-5. *System design with a siting at Forsmark.*

out the area. The indications found of local fracture zones suggest that they occur to a normal extent. A deep borehole at the Forsmark NPP shows a low fracture frequency throughout (1–3 fractures per metre), aside from a zone at a depth of 320 metres. The latter zone is interpreted as a gently-dipping fracture zone. Since such a zone has also been encountered at SFR, there is reason to assume that flat fracture zones also occur in the identified area. Rock stress measurements in Forsmark indicate high stresses below the aforementioned zone; otherwise, normal conditions are noted.

Rock stresses

Natural loads caused by the dead weight of the rock and geological processes

The overall picture that emerges is homogeneous gneissic granite rock and normal conditions with regard to fracture frequency and local fracture zones. It is probable that one or more flat fracture zones occur in the uppermost kilometre. Rock stresses can be elevated, mainly near the subhorizontal zones. The groundwater at repository depth is probably saline. Taken together, these are properties that are deemed good from a repository viewpoint, even though certain questions such as rock stresses, occurrence of subhorizontal fracture zones and permeabilities need to be cleared up, see Chapter 14. The Forsmark area is relatively small viewed as a base area for a site investigation. However, there is plenty of space for a deep repository, even if a site investigation should lead to dismissal of parts of the area as unsuitable.

As regards siting of a deep repository in a tectonic lens, Uppsala University, which has reviewed the feasibility study of Östhammar Municipality, writes: "The lenses are judged to be very interesting, since they could constitute a type of rock blocks suitable for a deep repository. Extensive field studies and geophysical interpretations, drilling etc. are required to determine if this is the case, which means that this falls for the most part under a possible site investigation."

Approximately 15 kilometres west of Forsmark is the Finnsjön study site, where SKB has previously conducted in-depth investigations /11-10, 11/. There are geological similarities between the Finnsjön site and the Forsmark area; for example, both lie in tectonic lenses and both have the same principal rock type. The positive assessment that was made of the Finnsjön site in the SKB-91 and SR 97 safety assessments can therefore be an argument for the Forsmark area as well.

Conditions for rock construction in the Forsmark area are judged to be similar to those at SFR, although a deep repository would involve rock construction at greater depth and larger rock volumes. Experience from the construction of SFR is very encouraging. With the exception of the Dannemora Mine, there are no rock facilities at repository depth in the region. Experience from Dannemora is good, but the geological conditions there are hardly comparable to those in the Forsmark area. All in all, there is no reason to believe that the prospects for building and operating a repository in the area in question at Forsmark are significantly poorer than is normal for Swedish bedrock.

Industrial establishment

With a system design as shown in Figure 11-5, overland transport of nuclear waste on public roads and rail lines is avoided, which SKB regards as a significant advantage. Other advantages are minimal environmental impact due to the utilization of existing industrial land and infrastructure, and coordination gains obtained from operation of the two repositories. Rock spoils from construction of the deep repository can be used as fill in the water area near the harbour, just as when SFR was built. It is estimated that about half of the spoils will be needed for backfilling the deep repository. The rest can be sold, whereby shipping directly from the harbour is a possibility.

In general, the Forsmark alternative thus provides good opportunities for limiting the environmental impact of the activities at the deep repository. The geologically interesting area has high natural values, however. A repository at a depth of 500 metres is not expected to disturb these natural values, but the question must naturally be examined and described in an environmental impact statement. What can impact the environment, and particularly the sensitive bird life in the area, are the site investigation activities. Site investigations must therefore be planned so that the natural values are taken into consideration. This may, for example, entail that drilling near sensitive areas is avoided at certain times of the year. If the site investigations should lead to establishment of a deep repository within the area, shafts will probably be needed directly above the repository for ventilation and evacuation of the repository. There is great flexibility in positioning these shafts so that sensitive natural environments are avoided. Few landowners would be directly affected by an establishment at Forsmark.

SFR

Final Repository for Radioactive Operational Waste, situated beneath the sea outside Forsmark. A total of approximately 0.5 million cubic metres of rock have been excavated from this repository. An equal amount of rock was excavated during the construction of the Forsmark NPP. By comparison, it can be mentioned that the total tunnel volume of the deep repository is estimated to be 1-1.5 million cubic metres.

The site investigations may temporarily disturb the local bird life. They should therefore be planned so that these disturbances are limited. The impact of a deep repository on natural values shall be described in an environmental impact statement (EIS)

Societal aspects

SKB generally considers the prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository in Forsmark to be good. Due to already existing large-scale nuclear activities, the site is perceived as a natural choice. The fact that a siting at Forsmark also means that overland transport of nuclear waste on public roads and railways can be avoided is seen by many as a strong argument. Other siting alternatives in the region can probably be accepted, but only if it becomes obvious that the bedrock in Forsmark is unsuitable or that the area cannot be accepted for other reasons.

11.3.5 Hargshamn

Hargshamn offers similar siting prospects as Forsmark. The area judged to be potentially suitable for a deep repository is located west of highway 76, see Figure 11-4, and is a tectonic lens in this case as well. The principal rock, gneissic granite (metagranite), is the same as in the Forsmark alternative. This rock covers a surface area of roughly 20 square kilometres, if only the bedrock west of highway 76 is assumed to be available.

The harbour in Hargshamn is well-suited for all transport to and from the deep repository. Which system design is most suitable will depend on where the surface facilities can be located. Figure 11-6 shows one alternative, where the surface facilities are built on the industrial land which the municipality is preparing at the harbour. From there, a tunnel can connect the industrial facility with a repository west of highway 76. It may, however, be necessary for environmental reasons to locate the surface facilities in an operating area west of highway 76 instead. In that case, transport over the short distance from the harbour to this facility will be necessary.

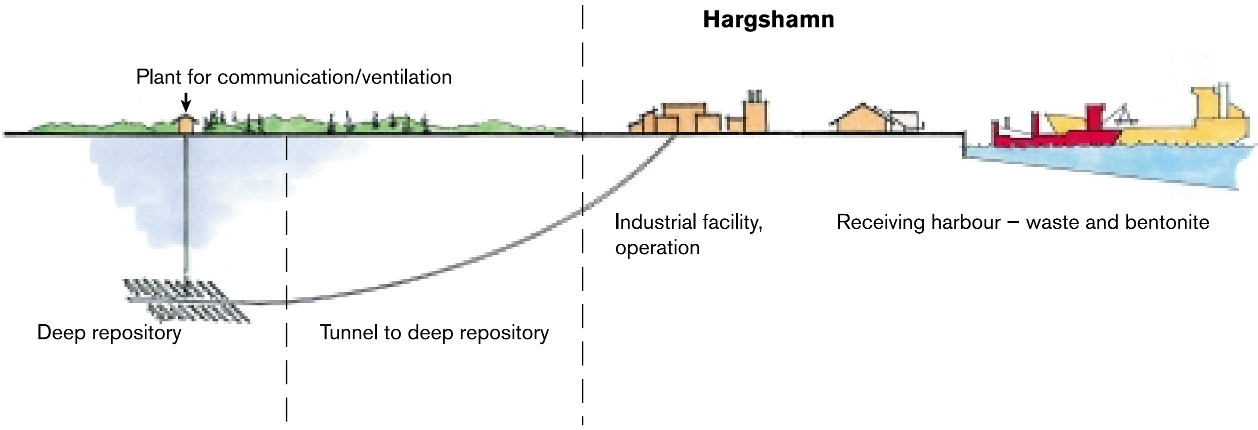


Figure 11-6. *System design with a siting at Hargshamn.*

Bedrock

The bedrock in the area in question at Hargshamn is judged to be homogeneous, with few indicated fracture zones and a low fracture frequency. The proportion of exposed rock is relatively high, which facilitates geological mapping and assessment of conditions at depth. SKB's assessment is that the bedrock may generally have conditions suitable for a deep repository. Due to the size of the area, there are good opportunities to deal with surprises during test drilling. Since evidence in the form of deep boreholes and underground facilities is lacking in the vicinity, no site-specific questions can be identified. The geological similarity with the Forsmark and Finnsjön area is used as an argument for the fact that the same site-specific questions can be expected for this area.

Industrial establishment

Hargshamn offers generally good technical prospects for building a deep repository. The system solution that is illustrated schematically in Figure 11-6 is judged to be the most suitable, both technically and environmentally. Since an existing industrial area at the harbour is utilized, the deep repository's facilities and activities can probably be designed so that environmental impact is limited and acceptable in relation to other activities at the harbour. The uncertainty as to whether this solution is possible to realize is due to the fact that the harbour and the area east of highway 76 lies in what the municipality's comprehensive plan calls a coastal and archipelago area, where the Environmental Code says that certain types of industries, including nuclear activities, may not be established. The alternative of siting the facilities west of highway 76 is presumably permissible under the provisions of the Environmental Code. However, this requires establishment of a new industrial area and some extra transport activity and is therefore regarded as a less desirable solution. If Hargshamn is considered for a site investigation, the possibility of siting its surface industrial facility at the harbour will therefore have to be carefully examined. Few landowners are directly affected by an establishment at Hargshamn.

The Environmental Code states that certain industrial plants, for example nuclear installations, may not be sited in the coastal area of southern Sweden, except where similar heavy industrial plants already exist

Societal aspects

As for Forsmark, SKB sees generally good prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository in Hargshamn. At the same time, the observation is made that a repository in Hargshamn has not been seriously discussed due to the fact that all of the above parties view Forsmark as a natural first choice. Since strong public support exists for a repository in the municipality, and since Hargshamn is presumably a technically and environmentally good alternative, it is probably possible to obtain acceptance for a site investigation there. A prerequisite is that site investigations in Forsmark have shown that the site is unsuitable for reasons that do not apply to Hargshamn, or that site investigations have not been able to be initiated in Forsmark for other reasons.

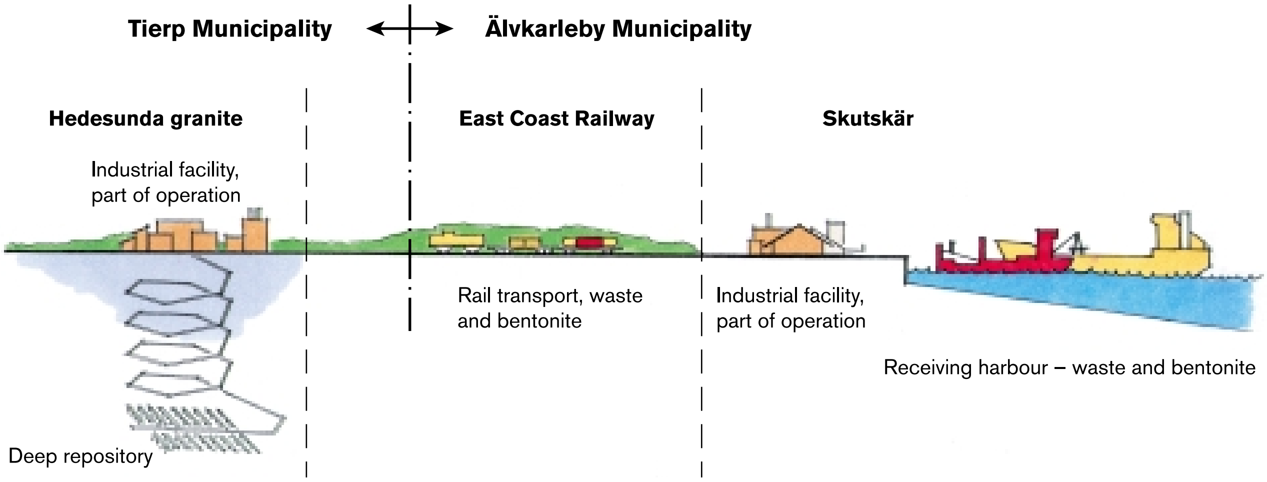


Figure 11-7. *System design with a siting at Tierp north/Skutskär.*

11.3.6 Tierp north / Skutskär

The priority area in the municipality of Tierp is the eastern portion of the granite massif named the Hedesunda granite. The area is approximately 60 square kilometres in size and borders in the west on the Uppsala Ridge, reaches in the south almost down to the town of Tierp, and extends northward up to the road between Västland and Marma, see Figure 11-4. Figure 11-7 shows a possible system design for this alternative. Skutskär is deemed to be suitable as a receiving harbour for waste and backfill material, as well as for shipping of rock spoils from the repository. A second-choice alternative is Hargshamn, which also has sufficient capacity, but would involve longer transport distances.

Transport takes place by rail. Skutskär has a connection to the East Coast Railway, which passes through the area in question in the municipality of Tierp. A branch line is built from the existing railway to the site for the deep repository's industrial facility. Further investigations are required before a site can be pinpointed.

Bedrock

The feasibility study's field checks /11-9/ and other data point to several factors that make the granite area north of Tierp potentially suitable for a deep repository. The size of the area should provide great freedom in a site investigation to locate a site that is suitable from a geological viewpoint, at the same time as technical and environmental requirements for establishment can be met. Further, the bedrock appears to be homogeneous, which provides good opportunities for general predictions of conditions at repository depth and between boreholes. The granite massif is probably deep enough (more than 1 km based on modeling of the gravity field), but this must be checked by deep drilling. One disadvantage is that the area has few outcrops, and that it is only covered by old geological maps. However, this drawback is judged to be compensated for by the fact that the investigations will be conducted in the same homogeneous granite massif, and that geophysical methods should be well applicable in this type of bedrock.

Granites can be either lighter or heavier than the surrounding bedrock. This affects the gravity field. This effect can be measured, and the size of the lighter or heavier body can be calculated

Besides the fact that the depth of the granite massif could be insufficient, the main factor that could make the site unsuitable is deemed to be high hydraulic conductivity. The feasibility study has also indicated the occurrence of dykes of fine-grained granite, which can exhibit elevated hydraulic conductivity and occur to such an extent that they affect the siting prospects. Boreholes are required to bring clarity in these questions.

The rock and the homogeneous geological conditions suggest favourable conditions from a rock construction point of view. Experience from rock construction at greater depth in this setting is, however, generally limited, so it is difficult to make judgements. One possible problem is high rock stresses, something which must be given special attention in a site investigation.

Industrial establishment

The alternative entails that industrial facilities are built within the area in question, at or near the site chosen for the actual repository. In general, the prospects of finding a suitable site for the surface facilities, with connection possibilities to the East Coast Railway and E4, are judged to be good. The landowner situation has not been fully clarified, but is preliminarily judged to be favourable (few landowners). Almost no special natural or cultural values are described in general plans. It should be emphasized that this is a superficial judgement; special natural or cultural values may be identified when concrete alternatives exist. At the same time, the nature of the deep repository's activities is such that there should be good possibilities of avoiding or limiting disturbances.

The possibility of locating parts of the operating activities at the harbour in Skutskär, instead of at the Tierp area, should be considered. The advantages of an existing industrial area (Skutskär) can then be exploited, at the same time as the environmental impact can be reduced in the area where new facilities must be established (the Tierp area). However, more detailed studies of the system design are required to determine which solution is the most suitable.

The harbour in Skutskär has generally good technical prospects, but a plan remains to be drawn up for how the different activities can be sited and designed in detail. This is work that must be done in cooperation with the owner of the harbour (Stora Enso), the municipality and other concerned parties. Because of its industrial structure, Skutskär may also be a possible site for other activities associated with the deep repository project, such as fabrication of copper canisters or components for such canisters.

Societal aspects

The municipal council was unanimous in its decision to permit a feasibility study. In a statement of comment on the preliminary final report, the municipality has requested modifications of and supplements to the feasibility study. SKB is now working on this.

The opinion surveys SKB has conducted in the municipality indicate support to move ahead to site investigations. At the same time there is active opposition to a site investigation, mainly from an opposition group and residents of Mehedeby. These people are worried about and opposed to the idea of a deep repository in the municipality. Common arguments advanced by opponents to a deep repository establishment are that the method is not approved, the process of selecting areas is flawed, and the image of the municipality will be tarnished.

In contrast to the alternatives of Forsmark and Hargshamn, a siting of the deep repository at Tierp would entail overland transport of nuclear waste on public transport routes. With the existing railway, the technical prospects for this are good. However, experience from other feasibility studies, mainly Storuman and Malå, shows that overland transport of nuclear waste causes concern that must be taken seriously. Special initiatives are therefore necessary, and the question must be discussed thoroughly with nearby residents of the railway and other concerned parties. More detailed and clear-cut information needs to be collected in further studies to shed light on nuclear waste transport and its consequences.

11.4 Södermanland - Nyköping

Figure 11-8 shows a key map of parts of Södermanland, with Nyköping Municipality. General information on Nyköping Municipality is summarized on the next page.

11.4.1 General prospects for a repository in the region

In general, the Nyköping region is judged to provide good prospects of establishing and operating a deep repository facility that satisfies the requirements on environmental consideration and technical function. Compared with Northern Uppland and Småland, Södermanland has more areas worth protecting that result in restrictions on siting. The possibilities of a siting on the coast are limited. In the municipality of Nyköping, it is only at the Studsvik facility that an establishment can be considered. There is only one other location along the entire coast of Södermanland where establishment of a new nuclear activity might be possible, namely at the steel mill in Oxelösund. However, the municipality of Oxelösund is not included in the selection pool for the siting of the deep repository. An inland establishment offers greater possibilities of finding suitable land for the facilities. The requirements that facilities and transportation system must be able to be operated with good technical function at the same time as environmental impact is kept to a low level nevertheless limit the choices considerably.

From a regional perspective, Södermanland has good resources in the form of industrial capacity, private and public services, and availability of labour. In Nyköping, know-how exists from metalworking, construction, design and nuclear activities. The municipality's location between Stockholm and the Norrköping/Linköping region offers good opportunities for commuting between these towns and for recruitment of labour. It also broadens the base of suppliers to the repository.

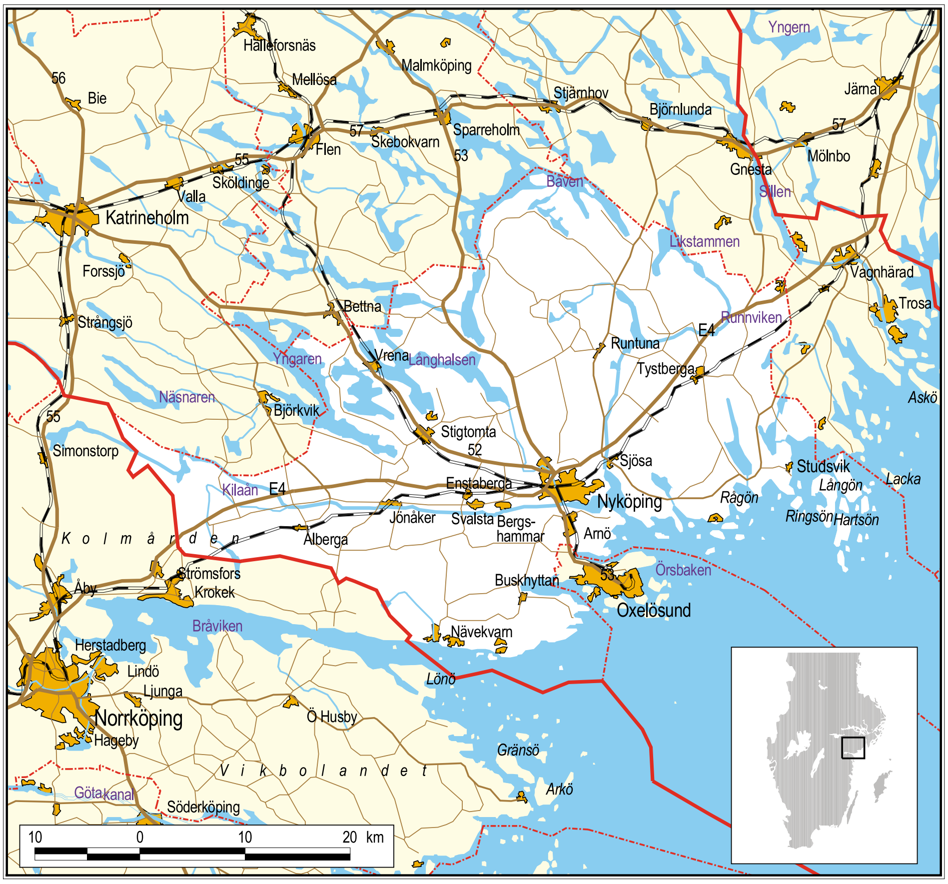


Figure 11-8. Nyköping Municipality.

Nyköping Municipality

The economic life of Nyköping Municipality has changed considerably during the past century. Industry has been replaced by services. Today the municipality has a broad economy characterized by a large public sector, a large private service sector and a small manufacturing sector. One large workplace is Studsvik with its companies in nuclear-related activities, with a total of 350 employees. Other large private employers are SAAB Automobile AB with some 375 employees and Thorsman & Co AB with some 225 employees.

The municipality is rich in cultural environments and historical monuments. Nyköping is one of the oldest cities in Sweden, and Nyköpingshus Castle has played a vital role in the country's history. There are many lakes in the interior of the municipality, such as Båven. The coastal and archipelago areas are important from a cultural and environmental viewpoint. The Nyköpingsån River, which discharges in the Baltic Sea via Stadsfjärden in Nyköping, is popular with anglers and canoeists.

Land area	Inhabitants
1,420 km^2	Approx. 49,000

Location
Coastal municipality in Södermanland County. The northern parts of the municipality border on the municipalities of Trosa, Södertälje and Gnesta, the western parts on the municipalities of Flen and Katrineholm, and the southern parts on the municipality of Norrköping. Oxelösund Municipality and the Baltic Sea are on the east.

Towns
Nyköping pop. 30,000, Stigtomta pop. 2,000, Svalsta pop. 1,000, Nävekvarn pop. 900, Tystberga pop. 900.

Transportation
Stockholm-Skavsta airport with both freight and passenger service. The E4 motorway passes through the municipality. Rail link with Stockholm and Norrköping/Linköping. A considerable part of the population commutes to Stockholm. Harbour for heavy goods traffic in Oxelösund.

Land
Approximately 52% forest land, 26% arable land and pastureland, 22% built-up and other land.

Political leadership
The seats in the municipal council are distributed as follows: Social Democrats 25, Left Party 6, Moderates 13, Christian Democrats 6, Centre Party 5, Liberal Party 3, Green Party 3.

Feasibility study decision
No decision in the municipal council.

Nuclear-related activities
Research facility at Studsvik, in operation since 1959.

11.4.2 Geological prospects for a repository in the region

The region is characterized by so-called Sörmland gneisses. This bedrock contains different types of metamorphic and gneissified rocks of mainly sedimentary, but also igneous, origin. Veins and large masses of igneous material often lie embedded in parts that are older. The rock is normally called sedimentary veined gneiss (metasediment) or just veined gneiss. There are also large areas in the region with more well-preserved massifs of gneissic granite (metagranite), where the metamorphosis has not been as extensive.

Both the above-mentioned principal rock types were formed approximately 1,900–1,870 million years ago, and their metamorphosis took place during the Svecokarelian orogeny approximately 1,850–1,800 million years ago. The degree of metamorphosis varies between different parts of the region.

The practical difference in connection with rock construction between veined gneiss and gneissic granite is presumably insignificant. Both rocks are generally considered to be favourable from a rock engineering viewpoint, as well as with respect to the long-term safety of a deep repository.

Other rocks present in the region are judged to be of less interest or unsuitable for a deep repository. These include volcanic supracrustal rocks, which often contain ore minerals. There are three orefields in Nyköping Municipality, known as the Tunaberg, Marieberg and Förola fields. There is no known ore potential in other parts of the municipality that would entail restrictions in the siting possibilities.

Sedimentary veined gneiss
This rock originally consisted mainly of clay and sand. By means of various processes, these layers have ended up at great depth in the bedrock and have been transformed there to gneiss

Igneous rock
Rock formed by the solidification of molten or partially molten bedrock (magma) in the interior of the earth

Meta = metamorphosed

The plastic deformation during the Svecokarelian orogeny gave rise to gneissosity, folding, plastic shear zones and foliation in the bedrock. More recent brittle deformation, through reactivation of the plastic shear zones or through formation of new fractures, has given rise to regional fracture zones with a primarily northwesterly orientation.

Reactivation
Displacements between rock blocks in a previously formed deformation zone

In the southwestern part of the municipality of Nyköping there is a complex pattern of large-scale plastic shear zones and a large number of fracture zones and faults. There are regional faults in the eastern part of the municipality as well, at the border to Trosa Municipality. The central and northern parts of the municipality largely lack plastic shear zones. Regional fracture zones occur here in a regular pattern with relatively large blocks of intact rock in between.

As a result of this geological history, the municipality of Södermanland/Nyköping is characterized by:

- Two principal rock types: sedimentary veined gneiss and gneissic granite.
- All rocks older than approximately 1,800 million years are gneissified, but the degree of metamorphosis varies between different parts of the municipality.
- The massifs of rock types younger than 1,800 million years old are small and/or heterogeneous.
- Ore potential, associated with bands of volcanic supracrustal rocks, exists in the central and southern parts of the municipality.
- Regional plastic shear zones are found primarily in the southern part. There are few such zones in the rest of the municipality.
- Regional major fault zones are found primarily in the southern and eastern parts of the municipality.
- Regional fracture zones, preferably with a northwesterly orientation, occur throughout the region.

The proportion of exposed rock is high in the coastal area, but there are large areas with a high proportion of exposed rock in other parts of the region as well. Modern geological maps cover large portions of the municipality.

Taken together, the geological conditions entail that approximately one-third of Nyköping Municipality was judged in the feasibility study as being of interest for further studies. This land is distributed between two large areas, see Figure 11-9.

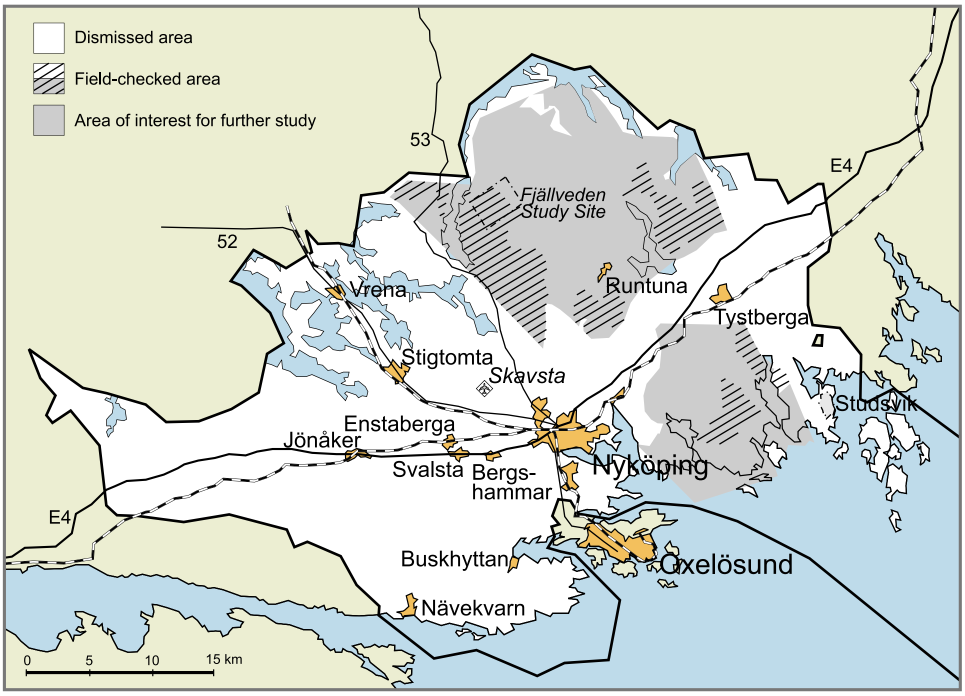


Figure 11-9. *Feasibility study's assessment of the bedrock in the municipality of Nyköping.*

In the municipality of Nyköping there is a study site, Fjällveden, where SKB has previously conducted in-depth investigations /11-12/. Among other things, a large number of holes were drilled down to a depth of 700 metres. Data from the investigations were evaluated in the KBS-3 safety assessment. The conclusion was that good geological and hydrological prospects exist for a repository in the area, but that supplementary investigations are required before this can be established. A similar geological environment exists on another study site, Gideå near Örnsköldsvik /11-13/. This site was evaluated in the SR 97 safety assessment (see Chapter 7). The assessment showed that a repository there would satisfy the safety requirements with good margin.

11.4.3 Siting alternatives

In the feasibility study of Nyköping Municipality, SKB has studied two siting alternatives: one with the surface facility at Studsvik and the repository in the Björksund area, and one with the surface facility at Skavsta and the repository in the Fjällveden-Tunsätter area, see Figure 11-10. A study of a siting at Studsvik was included in the original work plan for the feasibility study. Just prior to the feasibility study's supplementation phase, both SKB and the municipality were of the opinion that the feasibility study should be supplemented with a study of the prospects for a siting in the interior of the municipality. After publication of the preliminary final report, SKB has therefore performed field checks of interesting areas and compiled supplementary studies regarding the prospects of siting the deep repository's surface facility at Skavsta.

11.4.4 Studsvik/Björksund

The meteorite impact that formed the round bay of the sea called Tvären occurred 460 million years ago. The diameter of the meteorite was probably about 100 metres

In the municipality's coastal area, the siting possibilities for the deep repository's industrial operation are limited to a siting adjacent to the Studsvik facility. However, Studsvik is situated in a geologically complex area between two regional northwest-southeasterly faults. It is also uncertain what impact on the bedrock the meteorite impact in Tvären has had. The possibilities of finding sufficiently large rock volumes with the necessary rock quality for a deep repository within the Studsvik Peninsula may therefore be limited. Another negative factor is the occurrence of a graphite- and sulphide-bearing rock in the northern portion of the area.

The geological conditions are judged to be significantly better west and northwest of Studsvik. Here, the area shown in Figure 11-10 has, after completed field checks, been prioritized for possible site investigations. Figure 11-11 shows the system design that would then be used. The harbour in Studsvik is used for waste transport. Backfill material (bentonite clay) can be imported to e.g. the harbour in Oxelösund, where it is transshipped to smaller ships that can be received at Studsvik. The deep repository's industrial facility is situated adjacent to the Studsvik facility. The repository, with planned location in the Björksund area, is then reached via a tunnel. It may be suitable to build a small plant for communication and ventilation on the site above the repository. Moreover, one or more ventilation buildings will probably be required along the path of the tunnel.

Bedrock

The Björksund area is dominated by fracture-poor and homogeneous gneissic granite. An approximately 15 square kilometre area has been judged to be particularly fracture-poor and homogeneous. The bedrock is well-exposed. The area is permeated by northwesterly trending fracture zones of varying length. The distances between major fracture zones are judged to be great enough for a repository to be situated in a rock block between two such zones.

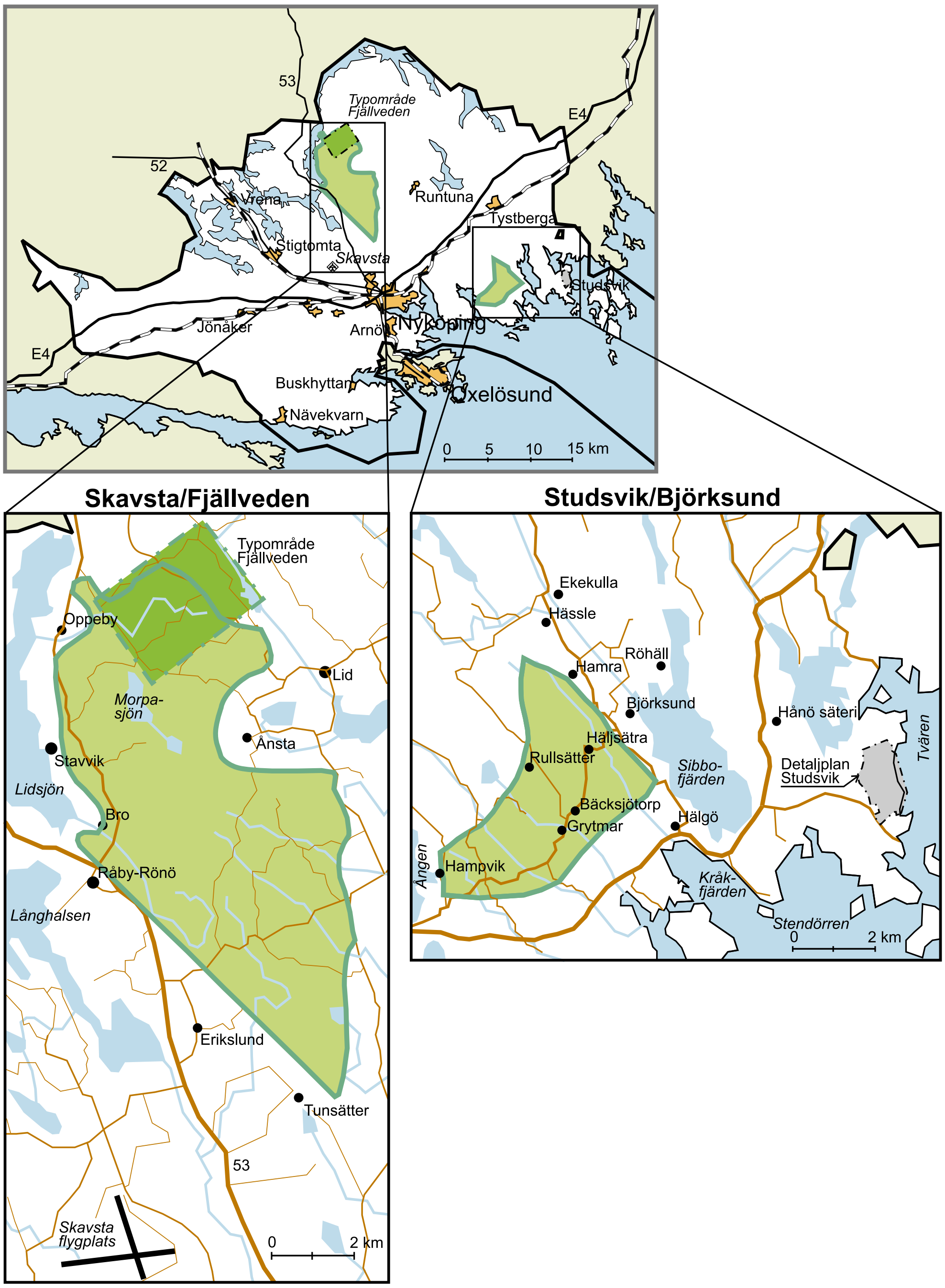


Figure 11-10. *The two areas in Nyköping Municipality that are judged in the feasibility study to be suitable for possible site investigations.*

Siting alternatives in Nyköping

- Studsvik/Björksund
- Skavsta/Fjällveden

The Björksund area is judged to offer good prospects for building and operating the deep repository's facilities. A connecting tunnel from Studsvik would pass through some of the aforementioned major fracture zones in the area. This is not deemed to be any appreciable technical obstacle, but special measures may be required to secure the tunnel against stability problems and unwanted groundwater impact.

As a possible alternative to Björksund there is the Ekekulla area, situated north-west of Studsvik (not marked in Figure 11-10), with equivalent geological conditions as far as can be judged. However, the Ekekulla area is smaller in size, and there is therefore a risk that the area will have to be abandoned if parts of it turn out to be unsuitable after more detailed studies.

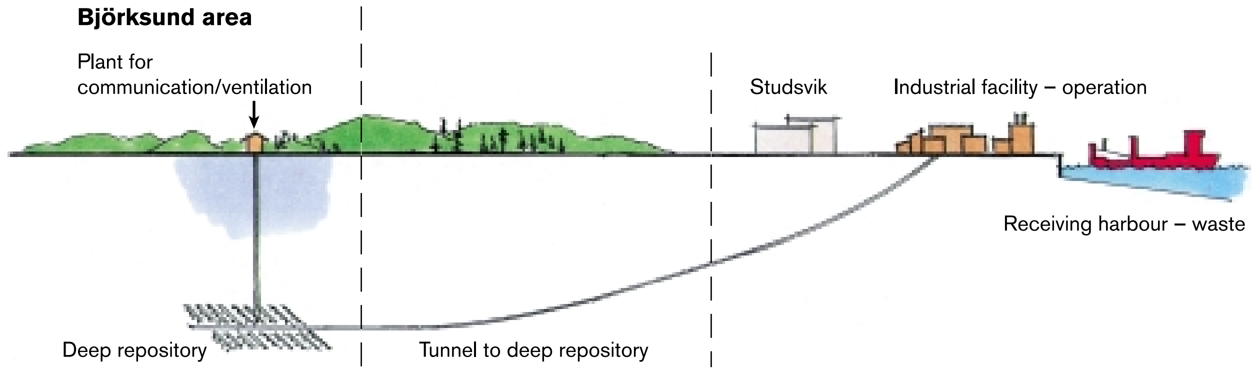


Figure 11-11. *System design with a siting at Studsvik/Björksund.*

Industrial establishment

With the existing harbour and the nuclear activities already on the site, Studsvik offers good technical prospects for repository establishment. The roads may need to be improved to handle the increased traffic entailed by a deep repository. Other necessary infrastructure already exists for the most part.

Two possible sites for the operating activities were identified in the feasibility study, both within Studsvik's fenced-in nuclear activities area. The one site contains an operating area large enough for the entire operation with all its functions. The other site accommodates only parts of the operation. By locating certain functions in rock caverns built in connection with the existing rock cavern for waste disposal, a good total solution can nevertheless be achieved.

Societal aspects

In contrast to other feasibility study municipalities, the municipal council in Nyköping has not made any decisions regarding the feasibility study. The following assessment is primarily based on discussions in the working groups that have followed and reviewed the feasibility study, as well as contacts with interest groups and the public during the course of the feasibility study.

Opinion polls point towards strong support among the public for the idea of moving ahead with a site investigation in the municipality. On the other hand, clearly expressed criticism was levelled at the Studsvik siting alternative in the feasibility study. Several reviewing bodies such as the county administrative board, the nature conservation society and other associations in the Tystberga district have proffered critical viewpoints on such a siting. Reasons offered, besides general criticism of the disposal method and the siting process, have included that the coastal area as a whole is much too sensitive with high natural, cultural and recreational values to permit the kind of industrial activities a deep repository would entail.

All factors considered, SKB concludes that the prospects of keeping and strengthening the support and confidence that exists for a siting in the municipality are generally good. This applies to both public opinion and the opinion among elected officials. There is greater uncertainty regarding attitudes towards the concrete siting alternative at Studsvik.

11.4.5 Skavsta/Fjällveden

Skavsta airport is located approximately six kilometres northwest of the town of Nyköping. Near the airport is an area with forest land that could be an alternative for the deep repository's industrial facility. North of Skavsta there are

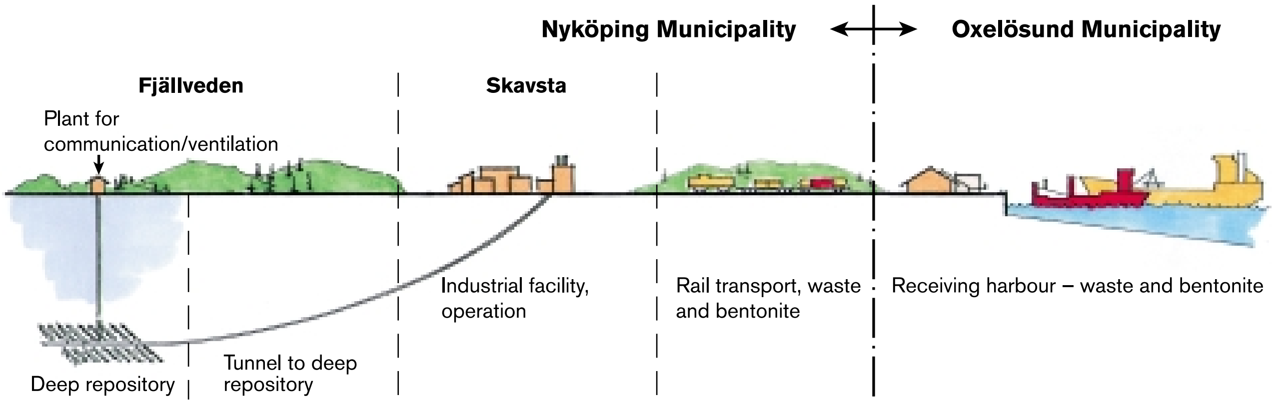


Figure 11-12. *System design with a siting at Skavsta/Fjällveden.*

good options for siting the deep repository's underground facility, primarily in the Fjällveden area, see Figure 11-10. SKB conducted extensive investigations in Fjällveden in the 1980s, including test drilling to the planned repository depth.

Figure 11-12 illustrates schematically a preliminary system design for the Skavsta/Fjällveden alternative. A prerequisite is that Oxelösund can be utilized as a receiving harbour for goods to the deep repository. Further transport to a facility at Skavsta can be effected by rail or possibly road. An approximately 15 kilometre long tunnel from Skavsta is the main alternative for further transport to Fjällveden. There may be other system solutions as well, for example road transport the entire way from Oxelösund to Fjällveden.

Due to the long distance between Skavsta and Fjällveden, a number of buildings and shafts for ventilation and communication are required on the site above the repository. In addition, one or more ventilation buildings are required along a possible connecting tunnel, as well as in the outer parts of the repository.

Bedrock

The extensive investigations that have previously been conducted in Fjällveden provided good knowledge of the bedrock and groundwater conditions in the area, even at repository depth. The assessment is that the area offers good prospects for both long-term safety and construction and operation of a deep repository. One of the factors contributing towards this assessment is low hydraulic conductivity. There are also good possibilities to further investigate and analyze the data collected in the previous studies.

One question that must be further investigated if the alternative is subjected to further study is how transport from Skavsta to a repository in the Fjällveden area can be solved. The distance is approximately 15 kilometres. If it should turn out that this distance causes great problems, a secondary alternative is to study the geological prospects in the southern part of the Fjällveden–Tunsätter area, see Figure 11-10. This area is located closer to Skavsta, and there is nothing to indicate that conditions in the area differ significantly from those in Fjällveden. However, more extensive investigations are required than in the Fjällveden area to verify this.

Industrial establishment

Skavsta/Fjällveden is preliminarily judged to be a feasible alternative from the establishment viewpoint. However, the prospects must be clarified in greater detail, particular as regards transport.

The identified area at Skavsta is intended for industrial activities. The transport infrastructure is good, and will probably be further built out in the future.

If transport from the harbour in Oxelösund to an industrial facility at Skavsta takes place by rail, the former TGOJ railway can be used. A 4–5 kilometre long branch line then needs to be built from the existing railway to the facility. Most of this line may be built anyway to meet the needs of the airport. Road transport may be an alternative, but this would presumably require extensive improvement and build-out of the road network.

Road or rail may be possible alternatives to a tunnel for further transport from Skavsta to Fjällveden as well, but then it will be necessary to build new transport routes.

Societal aspects

The alternative of a siting at Skavsta/Fjällveden has been proposed after circulation of the preliminary final report from the feasibility study for comment. It is therefore difficult to get a clear picture of attitudes towards this alternative. The preliminary studies done so far show that a siting at Skavsta/Fjällveden could work well, technically and environmentally. However, many questions remain to be cleared up before this alternative can be assessed with sufficient reliability. The uncertainties are mainly associated with the relatively great need for new transport routes and facilities.

11.5 Småland - Oskarshamn and Hultsfred

Figure 11-13 shows a key map of parts of Småland, with the two municipalities where feasibility studies have been done – Oskarshamn and Hultsfred. General information on these municipalities is summarized on the next page.

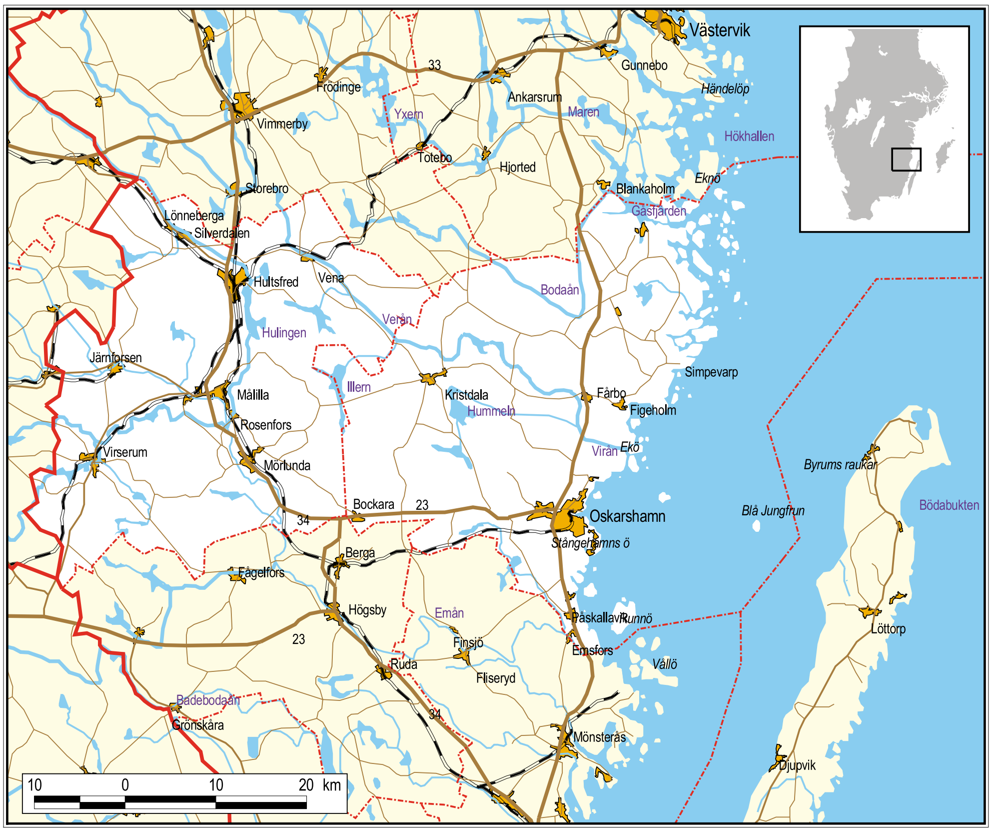


Figure 11-13. The municipalities of Oskarshamn and Hultsfred.

Oskarshamn Municipality

Oskarshamn is a forest and industrial municipality on the coast of Småland. The municipality used to be dominated by shipbuilding, agricultural and forestry. Today, engineering and energy are the dominant industries. The largest private employers are Scania with 1,600 employees and OKG with 1,000 employees at the Oskarshamn Nuclear Power Plant. SKB's facilities - CLAB, the Äspö HRL and the Canister Laboratory - employ some 170 persons.

Renowned tourist destinations are the Döderhultare Museum, the Simpevarp Peninsula with the NPP, CLAB and the Äspö HRL, and the Misterhult archipelago in the northern part of the municipality. The island of Blå Jungfrun (Blue Maiden) is a national park in Kalmarsund.

Location

Coastal municipality in Kalmar County. Borders in the north on the municipality of Västervik, in the south on the municipality of Mönsterås and on the inland side on the municipalities of Vimmerby, Hultsfred and Högsby.

Land area	Inhabitants
1,047 km^2	Approx. 26,500

Towns

Oskarshamn pop. 18,000, Figeholm pop. 1,000, Kristdala pop. 1,000, Påskallavik pop. 1,000.

Transportation

Airport with daily flights to Stockholm/Arlanda. Rail connections (passenger service) with Linköping and Kalmar. The E22 highway passes through the municipality in a north-south direction. Highway 23 leads westward towards Växjö. Oskarshamn has one of Sweden's biggest industrial ports with large exports of sawn timber products. Ferry service to Gotland.

Land

Approximately 75% forest land, 7% arable land and pastureland, 18% built-up and other land.

Political leadership

The seats in the municipal council are distributed as follows: Social Democrats 22, Left Party 10, Moderates 9, Christian Democrats 6, Centre Party 2, Liberal Party 1, Green Party 1.

Feasibility study decision

October 1996 - 38 yes, 5 no.

Nuclear-related activities

- Oskarshamn NPP with three reactors, the oldest in operation since 1974.
- CLAB (Central Interim Storage Facility for Spent Nuclear Fuel) in operation since 1985.
- Äspö HRL (research method development for the deep repository), completed 1995.
- Canister Laboratory (development of encapsulation technology for the deep repository), in operation since 1998.

Hultsfred Municipality

Hultsfred is heavily dominated by industry and agriculture. More than one-third of the jobs are in the manufacturing industry, where engineering and wood processing are predominant. The largest private employers are MoDo Paper AB with some 200 employees, Swedspan AB with some 150 employees, and Bergs Sågverk with some 140 employees.

Most Swedes connect Hultsfred with the annual Hultsfred Rock Festival. The municipality also has many lakes and watercourses, including the Emån River, offering wide opportunities for outdoor activities.

Location

Inland municipality in Kalmar County. Borders in the north on Vimmerby, in the east on Oskarshamn, in the south on Högsby and Uppvidinge, and in the west on Vetlanda and Eksjö.

Land area	Inhabitants
1,125 km^2	Approx. 15,300

Towns

Hultsfred pop. 5,500, Virserum pop. 2,100, Målilla pop. 1,700, Mörlunda pop. 1,100.

Transportation

Airport with scheduled service to Stockholm/Arlanda. Rail connections with Stockholm, Nässjö, Oskarshamn, Linköping and Kalmar. Highway 34 runs through the municipality in a north-south direction. Dackeleden, an alternative to E4 between Linköping and Malmö, runs through the municipality. The nearest major harbour is in Oskarshamn (about 60 km).

Land

Approximately 65% forest land, 30% arable land and pastureland, 5% built-up and other land.

Political leadership

The seats in the municipal council are distributed as follows: Social Democrats 19, Left Party 7, Moderates 5, Christian Democrats 7, Centre Party 8, Liberal Party 1.

Feasibility study decision

May 1999 - unanimous.

11.5.1 General prospects for a repository in the region

The municipalities of Oskarshamn and Hultsfred are both judged to offer good prospects of establishing and operating a deep repository facility in a way that satisfies all requirements on environmental consideration and technical function. The region has, with good margin, the resources needed for both the deep repository and other facilities and activities. Oskarshamn has the greater resources of the two municipalities, due to a larger population and a broader business range. The difference is not deemed to be of any decisive importance. Further, the distance between the localities is small enough for daily commuting, which tends to even out local variations in the supply of labour.

Besides generally good societal prospects, OKG's and SKB's existing and planned activities offer advantages that are in some respects unique for the country. Together with the activities at CLAB, OKG's presence provides an excellent base for recruitment of nuclear competence in the event of a deep repository establishment in the region. Further, SKB's activities at the Äspö HRL and the Canister Laboratory exist as knowledge bases which can significantly facilitate an establishment, especially in the start-up phase.

The possibilities of a siting on the coast are limited due to restrictions following from the Environmental Code. Possible coastal locations are nevertheless Simpevarp, with existing nuclear activities, and the industrial area in the Oskarshamn harbour. The limitations in the interior are fewer, but the inland locations can entail disadvantages from e.g. a transport viewpoint.

11.5.2 Geological prospects for a repository in the region

The rocks that dominate the municipalities of Oskarshamn and Hultsfred fall within the concept of Småland granite. This is a collective term for the relatively well-preserved granites that are so widespread in the region. The Småland granites were formed approximately 1,900–1,650 million years ago, after or in the final phase of the Svecokarelian orogeny that affected large parts of eastern Sweden. They are therefore affected relatively little by the plastic deformation and metamorphosis that is otherwise so common in our crystalline basement.

The bedrock in the region is characterized by:

- Dominance of Småland granite.
- Often good homogeneity over large areas.
- A varying presence of hypabyssal rocks and other heterogeneities.
- Almost total absence of ore potential.
- Small degree of metamorphosis and plastic deformation.
- Few major plastic shear zones.
- Fracture zones on all scales, to an extent that is normal for Swedish crystalline basement.

Hypabyssal rock
An igneous rock in the form of a disc that has formed when magma (molten rock) has penetrated into a fracture, or otherwise intruded into the rock and solidified there

Due to a relatively high proportion of exposed rock and generally uniform bedrock conditions, data and predictions from the feasibility study phase are relatively reliable, in spite of the limited availability of modern geological maps in parts of the region.

In comparison with the predictions that can be made of the bedrock, the corresponding predictions of groundwater conditions at depth are more uncertain. Partly in the sense that the groundwater conditions are in themselves far more difficult to judge based on information from the surface. And partly in the sense that the deep borehole data that are available from the region indicate conductivity values that are relatively high on average in relation to what is measured on many other sites. The latter is a potentially negative factor, primarily because it can diminish the safety margins and lead to special requirements on adaptation of the repository, for example by avoidance of local rock units with high water flow.

The geologically interesting areas are distributed between what are from a groundwater perspective near-coast locations (nearly all of the municipality of Oskarshamn and parts of the municipality of Hultsfred) and inland locations (most of the municipality of Hultsfred). Saline groundwater at repository depth can be expected in near-coast areas, while fresh water can be expected in inland locations.

To sum up, a number of petrological factors are favourable for a siting in the region. This is particularly true of the dominant Småland granites. At the same time, questions remain here, as in other regions, that can only be answered by test drilling. Examples are the occurrence and frequency of dykes and fracture zones, the hydraulic conductivity of these zones and of the intervening rock mass, groundwater flow paths, and chemical and rock-mechanical conditions.

Rock-mechanical conditions

Rock stresses, the strength and deformation properties of the rock

11.5.3 Siting alternatives

Oskarshamn Municipality

The feasibility study showed that most of the northern part of the municipality, and large areas in its south, have bedrock that is judged to be of interest for further studies from a geological viewpoint, see Figure 11-14. A ranking of these areas on geological grounds was not deemed possible on the basis of the data from the feasibility study. The point of departure for selecting certain areas for field checks was therefore (besides the requirement of potentially suitable bedrock) the technical and environmental prospects for establishment.

On these grounds, two areas were selected for field checks, here called the Simpevarp area and Oskarshamn south, see Figure 11-15. The Simpevarp area refers here to the Simpevarp Peninsula and large areas to the west. The choice of the Simpevarp area is based on the fact that the deep repository's industrial

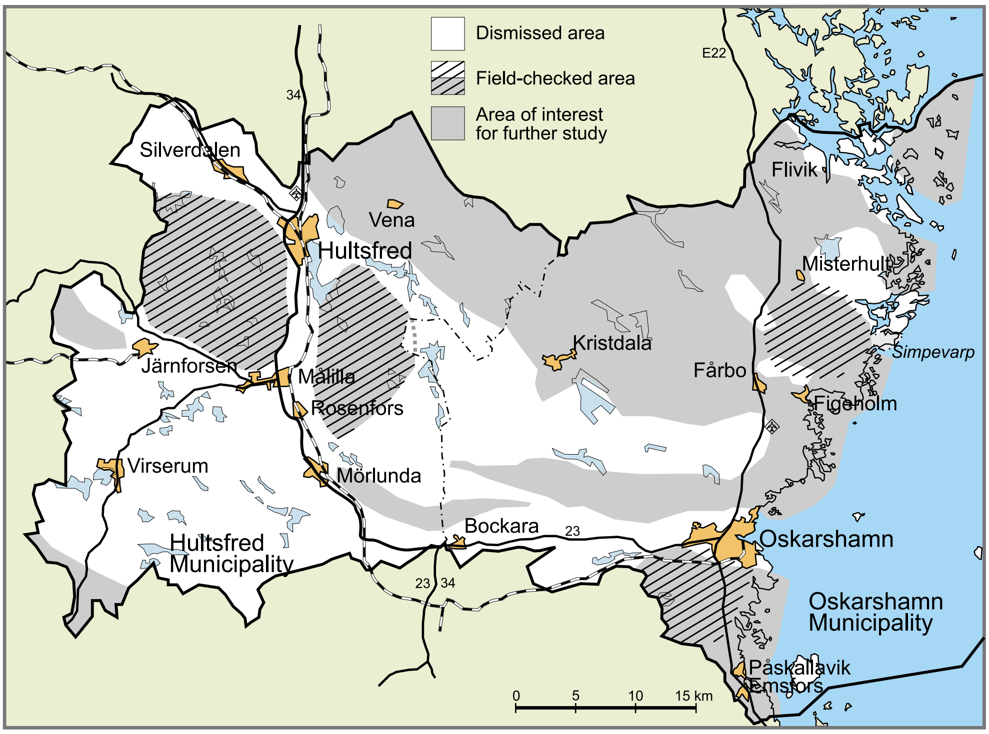


Figure 11-14. *Feasibility study's assessment of the bedrock in the municipalities of Oskarshamn and Hultsfred.*

operation can be co-sited with the existing facilities on the Simpevarp Peninsula and that the repository can be built in suitable bedrock at as close a distance as possible. The area in the southern part of the municipality (Oskarshamn south) was chosen because it opens up the possibility of a siting alternative with the repository inside the area in question, sea shipments to the Oskarshamn harbour, and surface operations either next to the harbour or at the deep repository.

The results of the field checks and other supplementary studies did not alter the previous assessment of the two areas as being of interest for further studies. Of the two alternatives, Simpevarp was prioritized due to the advantages of existing infrastructure and coordination possibilities.

Siting alternatives in Oskarshamn and Hultsfred

- Simpevarp
- Oskarshamn south
- Hultsfred east

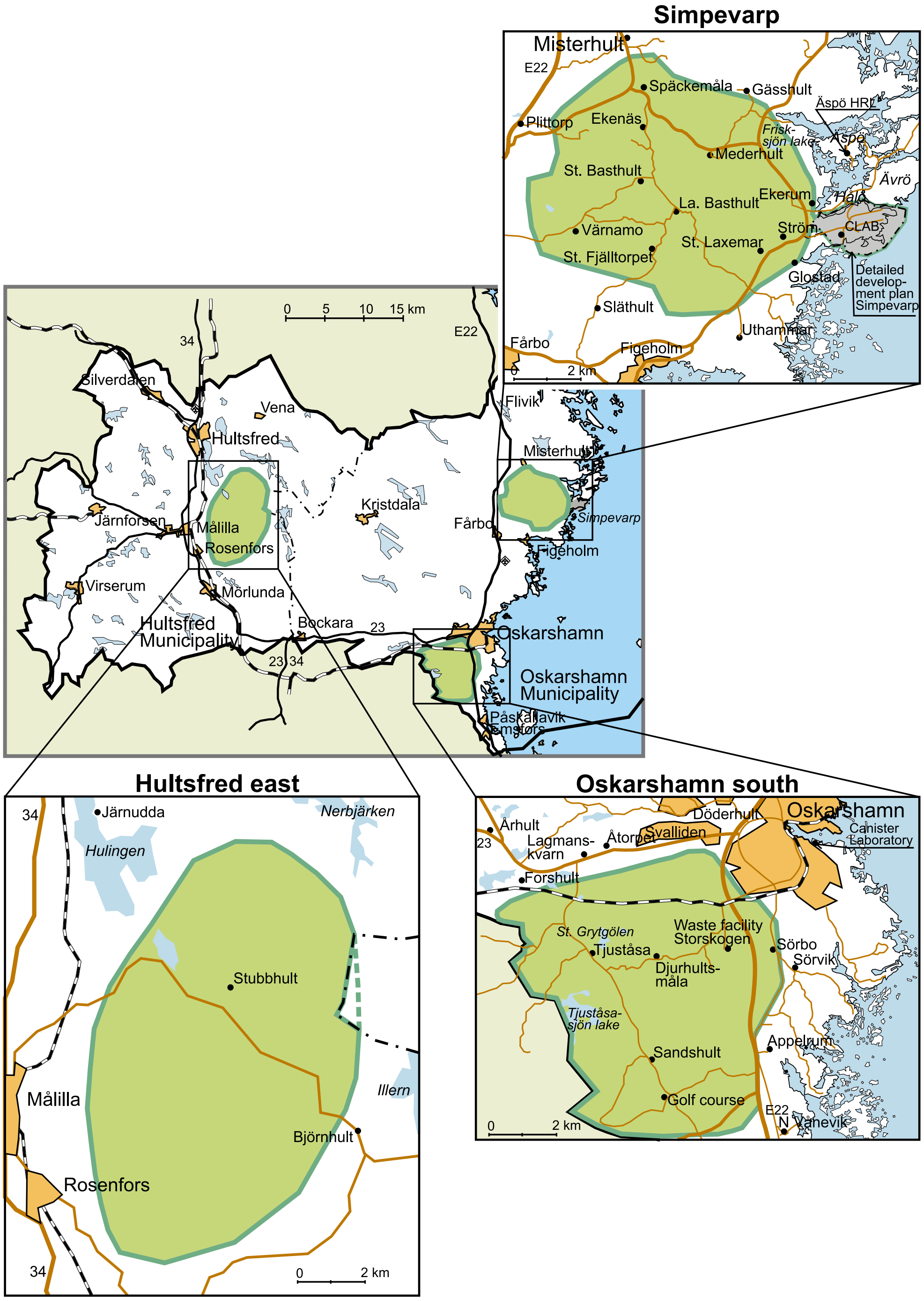


Figure 11-15. The three areas in the municipalities of Oskarshamn and Hultsfred which were judged in the feasibility studies to be suitable for site investigations.

Hultsfred Municipality

The feasibility study in Hultsfred indicated a number of areas where the bedrock was deemed to be potentially suitable for a deep repository, see Figure 11-14. The data from the feasibility study did not permit a ranking of the areas on geological grounds, but some were considered to be of less interest due to their comparatively small size. On the basis of studies of infrastructural and environmental siting prospects, two large areas were selected for field checks, one west of Hultsfred and the other east of Målilla.

The field checks verified the assessment of the areas as being of interest from a geological viewpoint /11-14/. With the support of this evidence and data on technical and environmental prospects, the area shown in Figure 11-15, here called Hultsfred east, has been prioritized for possible site investigations. A siting of the deep repository in this area would entail transport (mainly by rail) from a suitable harbour on the coast, plus construction of industrial facilities for the needs of the deep repository within the designated area.

11.5.4 Simpevarp

Bedrock deemed to be potentially suitable for a deep repository is located to the west of the Simpevarp Peninsula. The area deemed to be of interest has no geological boundary on the west. The delimitation in Figure 11-15 is preliminary and based on the preference of reasonable nearness to Simpevarp for reasons of system design.

Which system is the most suitable depends on where in the area the repository can be located. Figure 11-16 shows the main alternative, which entails locating the surface facilities within the existing industrial area on the Simpevarp Peninsula and the repository further west, within a distance that makes a connection via tunnel possible. A small plant for communication, ventilation etc. is probably needed above the repository. This alternative completely eliminates the need to transport waste canisters on public transport routes. Backfill material can be transported by large ships to Oskarshamn, since the Simpevarp harbour has limited capacity. Transport from Oskarshamn can be effected either by road, or by coastal tonnage that can dock at Simpevarp. Similar transport alternatives are available for dispatching rock spoils.

Bedrock

The conditions west of the Simpevarp Peninsula are for the most part typical of areas in the region dominated by Småland granites, with the possible exception of the fact that intrusions of other rock types are larger. Fracture zones of varying size are found to a normal extent. The fracture zones that have been interpreted on the investigation scale often border on rock blocks that are large

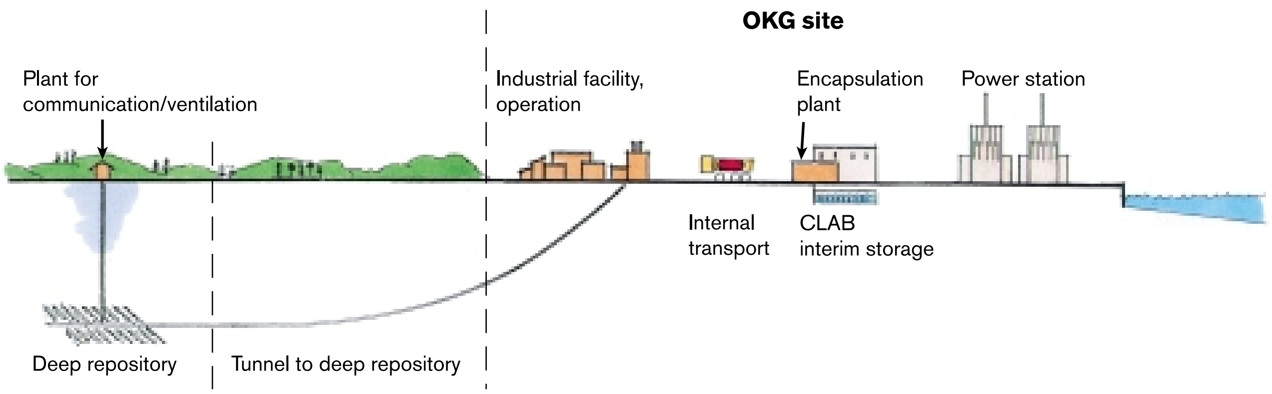


Figure 11-16. *System design with a siting in the Simpevarp area.*

enough to accommodate a deep repository. The availability of large areas with potentially suitable bedrock is judged to offer good possibilities of identifying a site that is geologically suitable for drilling in the initial phase of a site investigation, at the same time as it offers good siting prospects from other aspects. The area is distinguished by a relatively high incidence of granitic dykes. Like fracture zones, these heterogeneities should be given particular attention in possible further studies, since experience shows that they may be of importance for the hydraulic conductivity of the rock.

There are two deep boreholes in the Laxemar area, about three kilometres northwest of the Simpevarp Peninsula. These boreholes largely confirm the picture of the bedrock in the area that is obtained from surface investigations. Data from the boreholes can be compared with what is measured in boreholes at the Äspö HRL, but there is less variation in terms of occurring rock types. The groundwater is more saline, but the salinities are low down to a depth of around 1,000 metres. Hydraulic conductivity is mostly low in rock formations between fracture zones, but often high in the fracture zones intersected by the boreholes.

The bedrock on the Simpevarp Peninsula itself is intersected by a number of fracture zones and is generally more heterogeneous than further westward. It is therefore doubtful whether large enough rock volumes exist that are suitable from a safety viewpoint for the deep repository's deposition areas. The possibility should not be excluded, however. Depending on the system design that is chosen, the peninsula's bedrock can furthermore be of interest for other parts of the deep repository facility. A possible site investigation should therefore be aimed at ascertaining conditions at depth both on the Simpevarp Peninsula and west of there.

The prospects for building and operating the deep repository's rock facilities are judged to be favourable. This applies both to the Simpevarp Peninsula and the area west of there, and is based on good experience from the Äspö HRL and CLAB. This means good conditions, the need for adaptation mainly to fracture zones of various sizes, and probably an operating environment with saline groundwater.

Industrial establishment

If both the encapsulation plant and the deep repository are sited at Simpevarp, there will be no transport of encapsulated spent nuclear fuel, either by sea or over land. Transport of backfill material is required, however

The CLAB interim storage facility is located on the Simpevarp Peninsula, and SKB is studying the prospects of locating the encapsulation plant here as well. A siting of the deep repository on Simpevarp as well would entail that the entire spent nuclear fuel management system including interim storage, encapsulation, transport down to the deep repository and deposition would take place on the same site. Such a co-siting offers many advantages. The most important is that the need for long-distance transport of spent fuel, following transport to CLAB, is eliminated. Further, there are operational advantages to having a short handling chain and due to the fact that functions for e.g. radiological monitoring, maintenance and service can be co-utilized.

The feasibility study has shown that there is a suitable land area for the deep repository's surface facility within the existing industrial area, a few hundred metres from CLAB and the location of the planned encapsulation plant. Such a solution reduces the land need outside the industrial area to what is needed for whatever smaller facilities may be needed on top of the repository. This also reduces the environmental impact.

With the exception of the coastal area, which is subject to the Environmental Code's protection of certain coastal and archipelago areas, the area west of Simpevarp lacks protection values with the status of national interest. Forestry is conducted within the entire area. There is also agricultural land, but not much.

The area is split up into a large number of privately owned properties, many of which are relatively small. Such a landowner situation is a potential disadvantage from SKB's point of view. The attitude of the landowners who would be affected towards a possible deep repository establishment has not been fully clarified.

Societal aspects

SKB sees good prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository in the region and in the municipality of Oskarshamn. From this aspect, Simpevarp occupies a special position among possible siting alternatives in the municipality and the region. Due to the nuclear power plant and CLAB, Simpevarp is strongly associated with nuclear activities, making this site the natural choice for a deep repository as well in many people's view.

11.5.5 Oskarshamn south

The area marked in Figure 11-15 in the southern part of the municipality, here called "Oskarshamn south", is dominated completely by Småland granite. It is bounded on the north by an east-westerly system of zones with deformed bedrock and on the south by the municipal border. Furthermore, the stretch of coast south of Oskarshamn should be avoided out of consideration to restrictions on coastal sitings.

Figure 11-17 shows one of several possible system solutions for the Oskarshamn south alternative. The harbour in Oskarshamn is used for receiving nuclear waste and backfill material. In this alternative the deep repository's surface industrial facility is situated in the harbour area, from which a tunnel leads down to the repository. A small plant for communication and ventilation is then needed above the repository, along with ventilation plants along the path of the tunnel.

An alternative design is to locate the industrial facility in connection with the municipality's refuse plant (Storskogen) just southwest of the town and west of E22. Transport from the harbour to the facility can then take place by rail.

Bedrock

The previously presented general assessment of areas in the region dominated by Småland granite applies in all respects for the Oskarshamn south area. Geologically, the similarities with the Simpevarp area are great. The differences that can be noted are that the southern area is judged to be slightly more homogeneous petrologically speaking, and is almost completely lacking in hypabyssal rocks. Knowledge of bedrock conditions is poorer than for the Simpevarp area; there are, for example, no boreholes here, with the exception of wells for water supply.

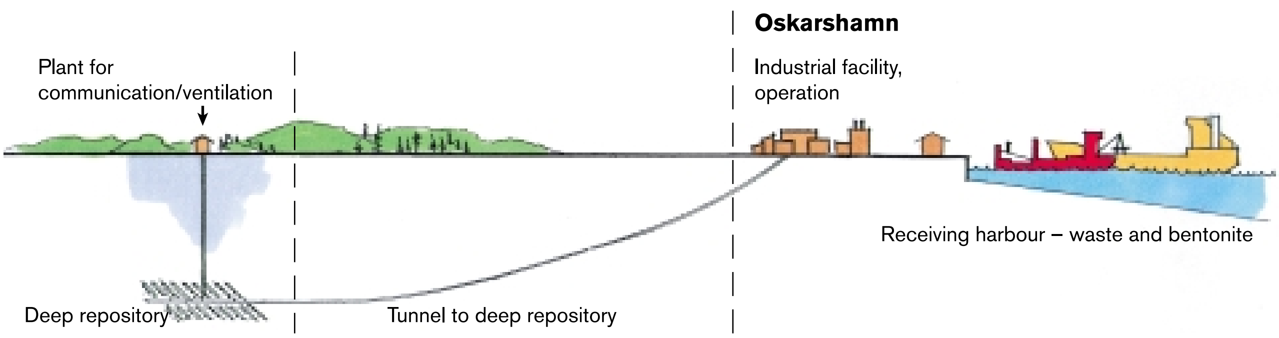


Figure 11-17. *System design with a siting in the southern part of the municipality of Oskarshamn.*

Conditions for rock construction and operation of the rock facilities are judged to be equivalent to those in the Simpevarp area. Since data from deep boreholes and underground facilities are lacking in the vicinity of the area, no site-specific questions can be identified. The geological similarity with the Simpevarp area could possibly be used as an argument that the same site-specific questions can also be expected for this area.

Industrial establishment

The harbour in Oskarshamn has high capacity and offers good technical prospects for all sea transport needed to and from a deep repository. A system design as shown in Figure 11-17 assumes that the deep repository's industrial facility is also located in the harbour area. The feasibility study shows good technical prospects for this. On the other hand it is unclear how large land areas can be made available for an establishment, taking into account other industrial activities within the harbour area. This should be clarified by any further studies of this alternative. The same applies to whether the contaminants (e.g. copper) from previous industrial activities present in the soil and sediment in the harbour might influence the possibilities of building new facilities.

An alternative to the design shown in Figure 11-17 is to locate the industrial facility adjacent to the municipality's refuse plant (Storskogen) just southwest of the town and west of E22, or possibly on the site above the repository. Transport from the harbour can then take place by rail. The space need in the harbour is limited for this alternative to a terminal for transshipment.

Due to utilization of the harbour and further transport from there (via tunnel or by rail), the facilities and activities will have some effect on the town. The area that is of interest for the repository is completely dominated by forest land. The possibilities of building the necessary facilities there are judged to be good as far as availability of suitable land and avoidance of conflicts with other land use interests are concerned. The area is divided among both large and small properties.

Societal aspects

SKB generally considers the prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository south of Oskarshamn to be good. At the same time, a repository in the area has not been discussed to a sufficient extent, since all of the aforementioned parties view Simpevarp as a natural first choice. Since there is strong public support for a repository in the municipality and Oskarshamn south is presumably a technically and environmentally good alternative, acceptance will probably be obtained for a site investigation there. But only if site investigations in Simpevarp have shown that the site is unsuitable for reasons that do not apply to the southern part of the municipality, or that it has not been possible to commence site investigations in Simpevarp for other reasons.

11.5.6 Hultsfred east

The area in the municipality of Hultsfred that is prioritized for further studies is shown in Figure 11-15. The area is approximately 75 square kilometres in size, with a bedrock composed almost exclusively of different types of Småland granite.

Figure 11-18 shows a possible system design for the Hultsfred east alternative. The main alternative for transport of encapsulated waste from Simpevarp is sea transport to the Oskarshamn harbour, and from there by existing railway via Berga, Mörlunda and possibly Målilla, and finally on a newly laid branch line to the site of the deep repository. The transport chain for this alternative would affect four municipalities: Oskarshamn, Mönsterås (marginally), Högsby and Hultsfred.

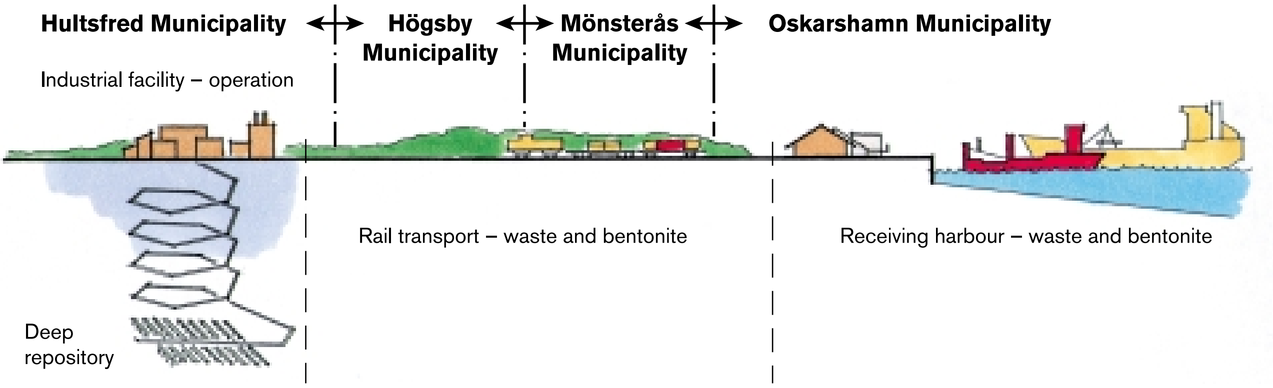


Figure 11-18. *System design with a siting in the priority area in the municipality of Hultsfred.*

The deep repository's industrial facility is built above the repository as a first-choice alternative, but other solutions are also possible. The feasibility study does not provide the data necessary to pinpoint a specific site for the facilities within the area of interest.

Bedrock

As far as the structure of the bedrock is concerned, it is difficult to point to any significant differences between the priority area in Hultsfred Municipality and other similar areas in the region, for example the area south of Oskarshamn described above. The positive assessment generally made of this geological setting from a repository viewpoint thereby also applies to Hultsfred east.

Since there are no boreholes to great depth in the area (or in the municipality), information is lacking on groundwater conditions at depth. When it comes to the water bearing characteristics of the rock, there are no reasons to assume that the conditions differ generally from what has been measured in deep boreholes in a comparable geological setting, i.e. above all in the Klipperås study site, the boreholes in the Laxemar area, and in part the Äspö HRL.

In view of the inland location and the fact that the area is situated almost completely above the highest coastline, fresh groundwater can be expected on good grounds at this repository depth as well. In comparison with conditions with saline groundwater, this can provide technical and economical advantages in the form of a reduced need for maintenance during the construction and operating phases. Lower costs are a plus in themselves, but a more important aspect can be the fact that the planning uncertainty is reduced. If it can be shown that the area will remain above sea level even during future ice ages, this provides further technical/economical advantages related to the choice of backfill material. Whether it is possible to take credit for these advantages is however uncertain and should be subjected to special study in a site investigation.

Fresh groundwater reduces maintenance costs. From a safety viewpoint, it is doubtful whether it is possible to design the repository based on the assumption of fresh groundwater, even after the next ice age

Since this area lacks deep boreholes and underground facilities, no site-specific questions can be identified. Here as well, the similarity with the bedrock in the Simpevarp area can be used as an argument that the same site-specific questions can be expected here.

Industrial establishment

The siting alternative of Hultsfred east would require establishment of new facilities and new traffic connections in an environment completely dominated by forest land. This entails disadvantages compared with an establishment where existing industrial land and/or infrastructure is available. However, the area is judged to offer wide options in choosing both site and design so that both the technical requirements and the requirements on environmental consideration and adaptation to other interests are met. The landowner situation in the area has not been fully clarified. It is difficult at this point to make any more detailed evaluations from an establishment viewpoint, since not enough geological data is available to pinpoint a priority site in the area.

A siting in Hultsfred requires comparatively long overland transport of waste and backfill material. The availability of suitable harbours and railways in the region offers good technical prospects for such transport. Disadvantages are uncertainty regarding the attitudes of the public towards such transport, risks of traffic accidents, environmental impact and costs. If the siting alternative is further studied in the site investigation phase, it is important that the transport question be studied in greater breadth and depth than has been done in the feasibility study.

Societal aspects

The generally positive evaluation made by SKB of the region as regards the possibilities of gaining the acceptance and support of society for the deep repository project also applies to Hultsfred. The uncertainties are judged mainly to apply to the transport question and the objections that may exist to any alternative that entails nuclear waste management on any other site in the region than the current one, i.e. Simpevarp.

12 Selection of siting alternatives for siting investigations

In order to proceed in the siting process, it is now SKB's task to select at least two sites for site investigations. In SKB's view, the siting alternatives from the feasibility studies provide a sufficiently large selection pool for this choice. After an integrated evaluation of the siting alternatives, three have been selected for test drilling: Simpevarp in Oskarshamn Municipality, Forsmark in Östhammar Municipality and an area north of Tierp in Tierp Municipality. The plans also include further studies of the prospects of a siting in Nyköping, but test drilling is not currently planned there.

The sites that are to be investigated represent different geological conditions and are situated in different regions and municipalities. This offers good chances that at least one site will ultimately meet all requirements. The choice also entails that the prospects of siting the repository in direct connection to two sites with existing nuclear activities will be investigated. If the bedrock on either of these sites is found to satisfy the requirements, the technical and environmental advantages provided by a co-siting with an existing nuclear installation can be exploited.

12.1 Selection pool

Chapter 8 describes the siting work that has been going on for nearly ten years now and the premises for the continued work. The process that has led to the selection of feasibility study municipalities and the principles for ranking of areas within each municipality are described in Chapter 11. A summary is given in the fact box on the next page.

The feasibility studies that have been carried out in a total of eight municipalities have resulted in the following eight siting alternatives:

Feasibility study Östhammar
Forsmark and Hargshamn, Forsmark is the priority area.

Feasibility study Tierp
Tierp north/Skutskär.

Feasibility study Nyköping
Skavsta/Fjällveden and Studsvik/Björksund. Skavsta/Fjällveden is the priority area.

Feasibility study Oskarshamn
Simpevarp and Oskarshamn south. Simpevarp is the priority area.

Feasibility study Hultsfred
Hultsfred east.

SKB's task, in accordance with the Government's statement in the decision regarding SKB's supplement to RD&D-Programme 92, is to select "at least two sites" for site investigations and to stipulate "the reasons for the choice of these sites".

12.2 Considerations for choice of sites

The fundamental point of departure for the continued work is the Nuclear Activities Act's provision that the reactor owners and thereby SKB bear responsibility for "ensuring the safe handling and final storage of nuclear waste arising in the activities". This provision means that SKB is obligated to come up with a solution that is both safe and feasible within a reasonable time span. The solution recommended by SKB is a KBS-3-type deep repository on a site in the Swedish crystalline basement. The site that is ultimately selected must have such characteristics that the regulatory authorities' safety requirements are satisfied. The establishment must also satisfy the other requirements made by society and be feasible.

Three fundamental questions to be answered prior to site selection are:

- Is the selection pool adequate?
- On how many sites should site investigations be conducted?
- How should the choice of sites be made?

The siting work for the deep repository

The guidelines for the siting of the deep repository are that:

- the repository shall be located in crystalline basement on Swedish territory,
- it must be possible to satisfy environmental, safety and radiation protection requirements,
- feasibility studies and site investigations are only conducted in municipalities that may have good geological and technical conditions and that wish to participate in the siting work.

The work has been under way since the early 1990s. It has been based on knowledge from study site investigations, general siting studies and safety assessments which SKB has conducted since the late 1970s. One main conclusion from the studies is that there may be sites in many of Sweden's municipalities that satisfy the requirements for a deep repository.

SKB presented a plan for the siting of the deep repository in the supplement to RD&D-Programme 92 submitted to the authorities in August 1994. The subsequent Government decision established the main elements of the process. At the same time, the Government stipulated that the supporting documentation for a siting application should be based on feasibility studies in 5-10 municipalities and at least two site investigations.

Feasibility studies

During the period 1992-2000, SKB has held more or less far-reaching discussions of feasibility studies with some twenty-odd municipalities in different parts of the country. In eight cases this has led to the execution of a feasibility study. In other cases the discussions have been called off, either because SKB found that a feasibility study was not warranted, or because the municipality decided to abstain.

The prerequisites for commencing a feasibility study have been fulfilment of the two criteria of suitable bedrock and voluntary participation. If a municipality has expressed an interest, SKB has first examined the existing geoscientific data to determine whether the bedrock in the municipality has justified a feasibility study. A general assessment has also been made of other siting factors.

Siting alternatives

The primary purpose of the feasibility studies has been to identify areas with bedrock that may have potential for a deep repository, and to rank them in order of priority based on an overall assessment of the siting prospects. The procedure has been as follows:

- Areas that do not have sufficiently good chances of satisfying the requirements on the bedrock are excluded.
- The remaining areas are preliminarily ranked, based on an overall assessment where technical and environmental siting aspects are also weighed in. Areas are selected for geological field checks.
- The results are presented in a preliminary final report, which is circulated for comment by the municipality along with other study material.
- Geological field checks and other supplementary work is done.
- All results are compiled, taking into account the viewpoints obtained from the commentary procedure. Siting alternatives are evaluated and ranked in order of priority. The whole feasibility study is described in a final report.

12.2.1 Is the selection pool adequate?

In its decision on the supplement to RD&D-Programme 92, the Government has stated that an application for a permit to build a final repository "should contain material for comparative assessments that shows that site-specific feasibility studies in accordance with SKB's account have been conducted at between 5–10 sites in the country". SKB has now carried out feasibility studies in eight municipalities, six of which are included in the selection pool. Viewed from this aspect, the selection pool is therefore adequate.

Another question is whether there are other siting possibilities aside from the selection pool that could offer such decisive advantages that they should be included in the selection pool.

Adequacy with respect to bedrock

The selection pool contains
- sedimentary veined gneiss
- gneissic granite
- younger granite

By means of study site investigations, general siting studies, research in hard rock laboratories and safety assessment, SKB has accumulated comprehensive knowledge of the geological conditions that are of importance for disposing of spent nuclear fuel in a deep repository. Figure 12-1 shows the location of the feasibility study municipalities on a geological map of Sweden. Northern Uppland is dominated by gneissic granites (brown on the map) and isolated massifs of younger granite (red). In Nyköping there are mainly gneissic granites (brown) and veined gneisses of sedimentary origin (light blue). In eastern Småland there are large coherent massifs of younger granite (red). Sedimentary veined gneiss, gneissic granite and younger granite represent different types of crystalline basement with differences in, among other things, plastic and brittle deformation.

Comparisons with safety-assessed sites suggest a good prognosis for all siting alternatives

The safety assessments that have been carried out in Sweden and Finland show that the safety requirements are satisfied with good margin for the sites that have been analyzed (see section 9.5). A fundamental conclusion drawn from the safety assessments and available geological knowledge is that the safety requirements can be satisfied for different geological conditions and on many sites. SKB concludes that the eight current siting alternatives have good chances of satisfying the requirements on the bedrock. This judgement is based on the material from the feasibility studies and on the results of safety assessments. Certain of the siting alternatives can be compared with the sites analyzed in SR 97. Thus, with regard to geological setting, comparison can be made between Simpevarp and Äspö (Aberg in SR 97), Forsmark and Finnsjön (Beberg), and Fjällveden and Gideå (Ceberg). Other siting alternatives also exhibit similarities that make them roughly comparable to one of the safety-assessed sites. At the same time, it is important to point out that safety is determined by local conditions, where knowledge can only be obtained by test drilling. Comparisons without this knowledge can verify a prediction, but cannot serve as an argument that a site really has the conditions required for a deep repository.

SKB's conclusion is that the selection pool represents an adequate geological breadth as a basis for continued selection of sites for the deep repository. There are thereby good chances that the requirements on the bedrock will be satisfied on at least one site. If further investigations on selected sites show that the safety requirements can be satisfied on one or more sites, there is no reason to search for sites elsewhere in the country.

Adequacy with respect to industrial establishment

Proposals for how the deep repository might be configured for the different siting alternatives have been devised in the feasibility studies. The least intrusion and environmental impact are obtained if existing industrial land can be used and if overland transport can be avoided. Co-siting with existing nuclear activities offers additional advantages, since these sites have infrastructure that suits the needs of the deep repository.

The selection pool includes both coastal locations involving only sea transport and inland locations that also require overland transport. There are a number of other coastal industrial locations that could also be of interest from the viewpoint of establishment and transportation. One example is at the oil refinery in Nynäshamn, with direct access to potentially suitable rock next to the existing deepwater port. However, the discussions with the municipality in Nynäshamn resulted in their rejection of a feasibility study due to the opinion that was formed when the discussion was initiated.

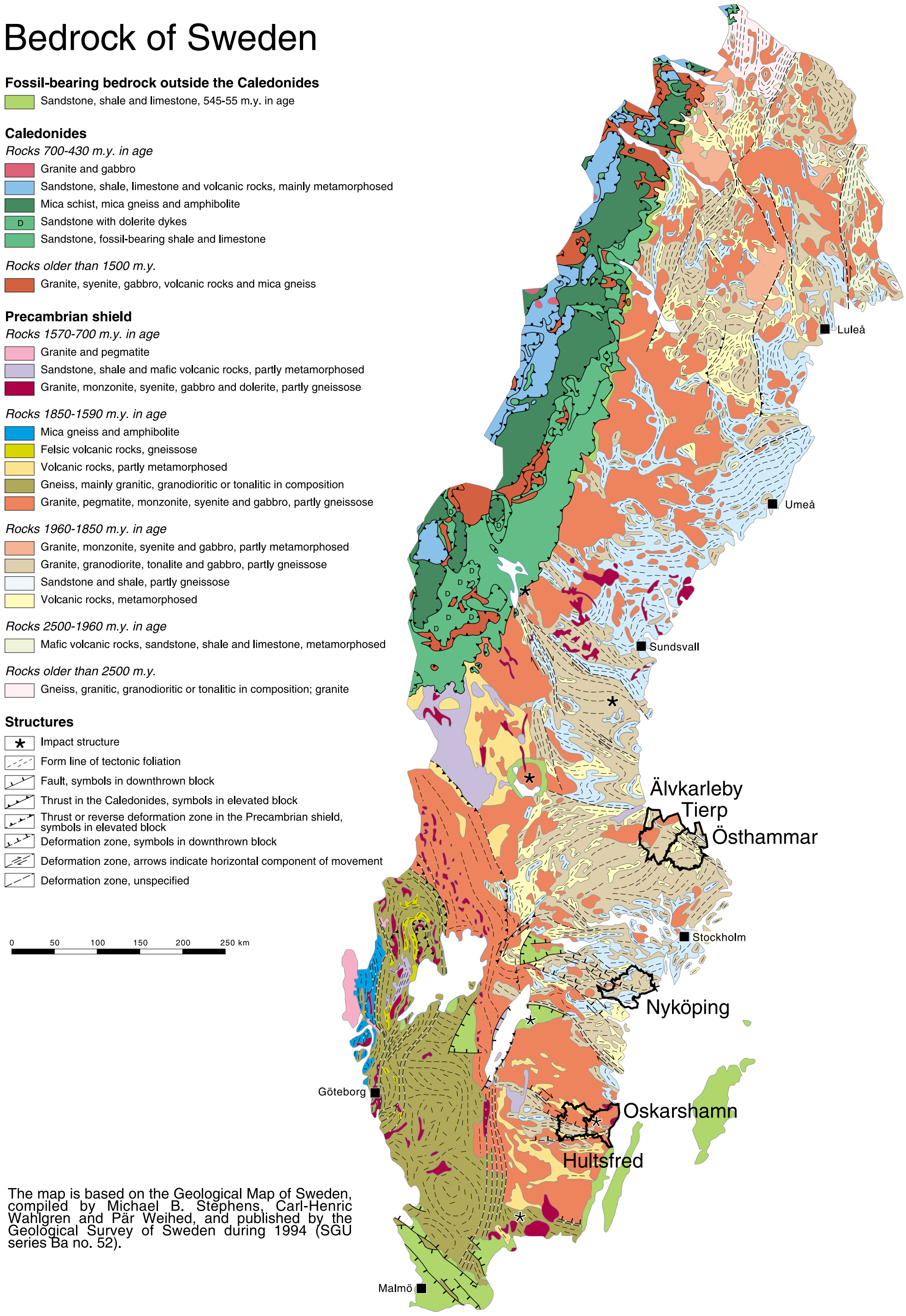


Figure 12-1. *Geological map of Sweden showing the feasibility municipalities.*

Light blue

Supracrustal rocks, mainly sandy and clayey sediments that have been metamorphosed to gneiss during an orogeny under relatively high pressure and high temperature.

The metamorphosis has sometimes given rise to veins of varying mineral composition. The rock is then termed sedimentary veined gneiss

Brown colours

Older granites and associated rocks. They have also been affected by relatively high pressure and high temperature during an orogeny. This impact has given rise to mineral orientation in the granite, which is therefore termed gneissic granite

Red

Different kinds of granites and associated rocks that have been formed towards the end of or after an orogeny. They are often homogeneous and have no or weak mineral orientation. They are sometimes termed younger granites

Adequacy with respect to societal aspects

The six municipalities included in the selection pool have chosen to participate actively and enthusiastically in the feasibility study work. SKB judges, based e.g. on opinion surveys, that there are good prospects for continued participation by these municipalities. There are other municipalities in the country that have initiated or wish to initiate a discussion with SKB on participation in the siting work for the deep repository. However, there is nothing to suggest that the societal prospects are better in other municipalities than in those now included in the selection pool.

SKB's conclusion

SKB concludes that the siting work should proceed with site investigations, since the selection pool contains sufficiently many alternatives for which the prospects of satisfying the safety requirements and implementing the deep repository project with the support of the community are good.

12.2.2 On how many sites should site investigations be conducted?

The fundamental point of departure for the choice of sites for site investigations is SKB's task of realizing a deep repository within a reasonable time on a site where the safety requirements can be satisfied. The choice will be made among the eight siting alternatives that have been arrived at in the feasibility studies. Although the prospects are judged to be good for all siting alternatives, questions remain that must be answered before it is possible to conclude that the requirements can be satisfied. Viewed from SKB's perspective, this involves a risk that must be evaluated and managed.

Eight siting alternatives to choose from

One theoretically possible strategy would be to select only one site for site investigations. This would be the most efficient alternative in terms of time and resources if the site is ultimately found to satisfy the requirements. However, if the requirements are not satisfied, investigations would have to be commenced on a new site. If this is discovered at a late point, the time taken by the site investigation phase would be more than doubled. There is also a risk that the siting programme might be called into question, which could make it impossible to commence investigations on a new site.

One way to reduce the risks of failure is to investigate more than one site. In principle, the more sites that are investigated, the greater is the possibility that at least one of them will ultimately satisfy the requirements. On the other hand, investigations on more sites mean that the site investigation phase requires more resources and takes longer time. Moreover, the engagement of politicians and the public is required in more municipalities during a longer period of time. This can be difficult to maintain, since the likelihood of any particular municipality being chosen decreases as the number of alternatives that are investigated increases. Furthermore, since the siting of the deep repository inevitably causes concern and raises hopes, these aspects must also be taken into account.

SKB's conclusion is that more than one site should be investigated, in view of the risks to the execution of the siting programme that are associated with the investigation of only one site. This is also compatible with the Government's statement that investigations shall have taken place on at least two sites before a permit application is submitted.

Determining the number of sites involves a risk assessment of many mutually incomparable factors and can thus not be done strictly scientifically. SKB must determine what is reasonable with respect to the ultimate goal and an evaluation of the uncertainties associated with the siting alternatives. This is explained in section 12.4.

12.2.3 How should the choice be made?

It was observed in Chapter 10 that if the deep repository is to be realized, the requirements on the bedrock and on the industrial establishment must be satisfied, and the support of society and the local community must be obtained. The premises for ranking and selection among the siting alternatives based on the three assessment grounds are discussed below.

Bedrock

The safety assessments that have been performed in Sweden and Finland have shown that the safety requirements can be satisfied with good margin for the sites that have been analyzed. SKB's judgement is that the bedrock on all sites included in the selection pool has good prospects of satisfying the requirements on long-term safety.

Not possible to rank with regard to bedrock

One possible procedure for selection could be to try to rank the sites based on what is known today, for example by strictly formulating geological factors for all areas and weighting them with respect to their importance in a safety assessment. Examples of factors that could be used in this phase are soil cover, homogeneity of the bedrock and fracture frequency on outcrops. The risk, however, is that this could lead to unclear or misleading results, since all geologically interesting areas satisfy all requirements and most preferences that can be checked now, and the factors that distinguish the areas are all of little direct importance for safety. Furthermore, the available information is greatly determined by the thickness of the soil cover and the proportion of exposed rock, which can make comparisons between areas misleading. For example, the data from the feasibility studies may indicate more fracture zones in an area with a high proportion of exposed rock compared with a soil-covered area. It is also difficult to see how the weighting of the factors with respect to their importance in a safety assessment could be justified.

In view of the limited data available on the bedrock today, SKB does not believe it is justified to rank the sites from a safety viewpoint. The question of ranking on the basis of safety aspects has also been addressed by the Swedish Radiation Protection Institute in a letter to the Government, where SSI says:

> "It is, however, of decisive importance for SSI in the assessment of a geological repository whether the Institute's regulations concerning ambitions for protection of health and the environment in connection with waste disposal will be complied with. The regulations will not permit the selection of a solution that is poor from a radiation protection viewpoint in any municipality. They will stipulate a high safety level, and if the requirements are satisfied on several sites, there is no reason from a radiation protection viewpoint to rank them."

Industrial establishment

Possible to rank with regard to industrial establishment

When it comes to the industrial establishment, the deep repository does not differ essentially from any other industrial activity. The prospects for establishment of the deep repository differ between the different siting alternatives. These differences can be evaluated in relation to the requirements and preferences described in section 10.3. Provided that the bedrock satisfies the requirements, the evaluation of requirements and preferences for the industrial establishment can be used to rank the different siting alternatives in order of priority.

Societal aspects

It is important to obtain support for the siting of the deep repository both locally and nationally. This support requires formal confirmation in the form of favourable decisions by the concerned municipal council, regulatory authorities, the Government and the Environmental Court. It is a question of many decisions that are made over a long period of time. In the light of constant changes in society, it is difficult to apply the factors described in section 10.4 when selecting sites for site investigations. In the face of this choice, SKB has made the judgement that long-term local support for an establishment is essential. In view of possible changes in local opinion, the chances of obtaining support throughout the process on at least one site are greater if the selected sites are located in different municipalities. Nor does SKB want to take the risk of conducting site investigations on areas where it may be impossible in the future to establish nuclear installations for legal reasons.

12.3 Evaluation

In the following sections, an evaluation is made of the eight siting alternatives with respect to the requirements and preferences that can be judged today with regard to the bedrock, the industrial establishment and the societal aspects. The description of each alternative focuses on properties and conditions that are of importance for the choice at this point and on differences between the sites. The more detailed presentation of the sites given in Chapter 11 is not repeated here.

12.3.1 Bedrock

Each feasibility study selects a priority area for site investigations for each siting alternative. The judgement that was made in the feasibility studies is that all areas satisfy the requirements on the rock that can be checked in this phase, when essentially only surface data are available.

Table 12-1 summarizes distinguishing characteristics and important questions and uncertainties for the different areas.

Forsmark

The priority area between the Forsmark NPP and the bay of Kallrigafjärden is a part of a tectonic lens consisting of gneissic granite. The area is approximately 10 square kilometres in size, which is plenty for a deep repository. The area has a relatively high proportion of exposed rock. With information available from airborne geophysical surveys and relatively detailed geological mapping, and with experience from the construction of the Forsmark NPP and SFR, knowledge of the bedrock is judged to be relatively good. This has led to the identification of site-specific questions.

The location in a tectonic lens is judged to be advantageous from a hydrogeological and mechanical point of view, but this is not something that can be determined conclusively until borehole data are available. The area exhibits similarities with the geological conditions in the Finnsjön area. The positive assessment that was made of the Finnsjön area in the SKB-91 and SR 97 safety assessments (where it was called Beberg) can therefore serve as an argument for further studies of the Forsmark area. Site-specific questions are the extent of the lens in depth and the occurrence of high rock stresses, gently-dipping fracture zones and bedrock with ore potential at depth. These questions can only be answered by drilling.

Conclusion: The Forsmark area is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons for this judgement are the availability of a tectonic lens, which can be advantageous from a safety viewpoint, and positive experience from nearby rock excavation projects.

Table 12-1. Compilation of distinguishing characteristics and important uncertainties regarding the bedrock

Area	Distinguishing characteristics	Available data	Important questions and uncertainties
Forsmark	Gneissic granite Tectonic lens with homogeneous, fracture-poor rock Small area	Data from nearby rock facilities and boreholes Relatively high proportion of exposed rock	Importance of surrounding shear zones. Extent of lens in depth and size of favourable area at repository depth. Occurrence of gently-dipping fracture zones. High rock stresses. Bedrock with ore potential at depth
Hargshamn	Gneissic granite Tectonic lens with homogeneous, fracture-poor rock. Relatively big area	Only surface data Relatively high proportion of exposed rock	Location in a tectonic lens leads to same questions as in Forsmark No other site-specific questions can be identified, since only surface data are available
Tierp	Isolated massif of younger granite Homogeneous bedrock with granite dykes Flat soil-covered area Few interpreted fracture zones Big area	Only surface data Few outcrops	Frequency and hydraulic conductivity of granite dykes. Depth of granite No other site-specific questions can be identified due to limited surface data
Björksund	Gneissic granite Homogeneous bedrock with low fracture frequency The area has relatively many fracture zones. They have a dominant direction that gives the rock blocks an elongated shape Relatively big area	Only surface data High proportion of exposed rock	Size of favourable area at repository depth and adaptation of repository to fracture zones. Access tunnel to repository must pass several regional fracture zones, can cause construction problems. No other site-specific questions can be identified, since only surface data are available
Fjällveden-Tunsätter	Sedimentary veined gneiss Homogeneous bedrock with some gneissic granite Big area	Extensive database from study site Safety assessment KBS-3 (good forecast) Relatively high proportion of exposed rock	Occurrence, size and location of suitable bedrock blocks outside study site Access tunnel to repository must pass several regional fracture zones, can cause construction problems
Simpevarp	Large coherent massif of younger granite Homogeneous bedrock with some other rock types and dykes Fracture zones divide the bedrock into distinct rock blocks Big area	Extensive data available from Äspö and Laxemar Relatively high proportion of exposed rock	Size and location of bedrock blocks with favourable properties at repository depth Occurrence and importance of granitic dykes and fracture zones, particularly with respect to hydraulic conductivity
Oskarshamn södra	Large coherent massif of younger granite Homogeneous bedrock with few granitic dykes Big area	Only surface data Relatively high proportion of exposed rock	Size and location of bedrock blocks with favourable properties at repository depth No other site-specific questions can be identified, since only surface data are available
Hultsfred	Large coherent massif of younger granite Homogeneous bedrock with few granitic dykes Big area	Only surface data Relatively high proportion of exposed rock	Size and location of bedrock blocks with favourable properties at repository depth No other site-specific questions can be identified, since only surface data are available

Hargshamn

The area is located in a tectonic lens and exhibits geological similarities with Forsmark and Finnsjön. For this area as well, experience from the safety assessments in the Finnsjön area are an argument for further studies. The area is slightly bigger than Forsmark, approximately 20 square kilometres. In contrast to Forsmark, there are no rock facilities in the vicinity of Hargshamn. It has therefore not been possible to identify any site-specific questions.

Conclusion: Hargshamn is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons are a relatively large area with potentially suitable bedrock and the fact that a tectonic lens can offer advantages from a safety viewpoint.

Tierp north

The Hedesunda granite is a large granite massif which is younger than the surrounding bedrock. It has not been affected by plastic deformation to the same extent as e.g. Forsmark and Hargshamn. A priority area (approx. 60 square kilometres) exists for further studies. Within this area the granite is judged to be homogeneous, but there are dykes of fine-grained granite.

The advantages that can be identified are above all the homogeneity and size of the bedrock, few interpreted fracture zones and the low fracture frequency in the outcrops that have been checked in the field. The size offers flexibility to change drilling area if conditions are encountered that are judged to be unfavourable but local. The disadvantages that can be identified are mainly poor knowledge of the bedrock surface owing to few outcrops. The dykes of fine-grained granite may also be a disadvantage if they occur frequently and are permeable. The geological and geophysical nature of the area is such that surface and airborne geophysical surveys, together with the fact that the granite is presumably homogeneous over large areas, can largely compensate for the scarcity of data due to few outcrops. The reliability of the geophysical mapping needs to be verified by means of boreholes and trenches, however. It has therefore not been possible to identify any site-specific questions aside from those mentioned above.

Conclusion: The Tierp area is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons are the homogeneity of the granite, the size of the area, few interpreted fracture zones and a low fracture frequency.

Björksund

The area is approximately 15 square kilometres in size and consists of bedrock blocks of homogeneous gneissic granite with a low fracture frequency surrounded by northwesterly trending regional fracture zones. The local fracture zones inside the area are also principally northwesterly trending. The area has a very high proportion of exposed rock. The distance between the fracture zones is judged to be sufficient to enable a repository to be positioned between these zones. No site-specific questions have been identified.

Conclusion: Björksund is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons are the homogeneity of the gneissic granite and the low fracture frequency.

Fjällveden

The Fjällveden-Tunsätter area consists of sedimentary veined gneiss and gneissic granite. Fjällveden has previously been investigated by SKB and data are available on conditions at repository depth. The bedrock has low hydraulic conductivity and a low fracture frequency.

Data from Fjällveden were used in the safety assessment that was carried out within the framework of the KBS-3 study. The conclusion was that the area is probably suitable for a deep repository. This conclusion is probably applicable to more sites within the Fjällveden-Tunsätter area. The size of the area provides flexibility in the positioning of a deep repository.

Conclusion: The Fjällveden-Tunsätter area is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons are the size of the area and the good experience from Fjällveden.

Simpevarp

The area where the feasibility study has identified potentially favourable bedrock extends westward from the Simpevarp Peninsula. There is no geological boundary on the west. The area consists of Småland granite with dykes of fine-grained granite and other rock types. The size of the area provides flexibility in the positioning and layout of the deep repository. Within the area there are fracture zones that delimit bedrock blocks. The soil cover is thin and the proportion of exposed rock is relatively high. Knowledge of the characteristics of the Småland granite in the area exists from the Äspö HRL and boreholes at Laxemar west of Simpevarp. The site-specific questions that should be given special attention are the availability of sufficiently large and suitable bedrock blocks, the occurrence and importance of dykes, particularly fine-grained granites, and hydraulic conductivity in various rock types and in fracture zones.

Data from the Äspö HRL have served as a basis for the example of Aberg, which was analyzed in SR 97. From a safety-related viewpoint, SR 97 shows that it is possible to configure a deep repository on Äspö so that the safety requirements are satisfied, but at the cost of a split repository design due to a high concentration of fracture zones.

Conclusion: The Simpevarp area is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons are the large extent of potentially suitable bedrock and good experience from rock facilities in the immediate area.

Oskarshamn south

The geological setting exhibits similarities with the Simpevarp area, with the difference that the area is almost completely lacking in granite dykes. The proportion of exposed rock is relatively high. The main question in this area as well is identifying suitable bedrock blocks between fracture zones. In contrast to Simpevarp, experience is lacking from nearby rock facilities. It has therefore not been possible to identify any site-specific questions.

Conclusion: Oskarshamn south is deemed to be of interest from a geological viewpoint for site investigations. The foremost reasons are the homogeneity and expected good properties of the Småland granite and the size of the area.

Hultsfred east

The area is approximately 75 square kilometres in size and is dominated completely by Småland granite. The geological setting exhibits great similarities with Oskarshamn south. One difference is that the groundwater is probably fresh at repository depth in Hultsfred. This affects the operating conditions for the deep repository, but is probably of no importance for long-term safety.

Conclusion: The Hultsfred area is deemed to be of interest from a geological viewpoint for site investigations. Experience is lacking from rock facilities in its immediate area. It has therefore not been possible to identify any site-specific questions.

SKB's conclusion

The judgement that all areas have good potential for meeting the requirements remains valid. As is evident from Table 12-1, there are questions and uncertainties for all areas. It is thus not possible at this stage to exclude any of the areas on geological grounds. The areas represent different geological settings. The following classification can be made:

- Gneissic granite/tectonic lens (Forsmark, Hargshamn and Björksund)
- Sedimentary veined gneiss (Fjällveden)
- Isolated massif of younger granite (Tierp north)
- Large coherent massif of younger granite (Simpevarp, Oskarshamn south and Hultsfred east)

The selection pool includes four geological settings

Björksund is not situated in a tectonic lens, but the rock type is the same as in Forsmark and Hargshamn. There are similarities with Fjällveden as regards brittle deformation, for example the orientation of regional fracture zones.

The first two settings represent bedrock that has been affected by plastic deformation to varying degrees, which has taken various expressions. The last two have been affected relatively little or not at all by plastic deformation. Brittle deformation (fracturing) has affected all settings.

12.3.2 Industrial establishment

The requirements and preferences that are made on the deep repository as an industrial establishment are described in section 10.3. The feasibility studies show preliminarily that there are good prospects of satisfying these requirements and preferences in all priority areas, but supplementary studies are required to confirm this.

The prospects for establishing and operating the deep repository's facilities and the transportation system are evaluated in this section. In general, alternatives where existing industrial land can be utilized are valued more highly than ones where new land areas need to be utilized. Siting in connection with existing nuclear activities is deemed to be advantageous. Transportation should be able to be arranged in a simple manner. From this aspect, it is advantageous if existing transportation systems can be used and if few transshipments are required. If overland transport of spent nuclear fuel can be avoided, this is an advantage. It is favourable if there are few competing land use interests and few landowners. The preferences of availability of local resources for execution of the deep repository project (labour, service, etc.) are judged to be well satisfied for all alternatives and are therefore not taken into account in the evaluation. In the overall assessment, uncertainties with regard to the prospects of a deep repository establishment are also taken into consideration.

Advantages with respect to industrial establishment

- industrial land, extra advantageous with existing nuclear activity
- simple transport, extra advantageous if overland transport is avoided
- few landowners

Table 12-2 summarizes the establishment prospects as well as special advantages and disadvantages for the different siting alternatives. The transport needs indicated in the table pertain to encapsulated spent nuclear fuel and do not include transport of backfill material, rock spoils etc., see Chapter 11.

SKB makes the following evaluation of the establishment prospects for the different siting alternatives.

Table 12-2. Prospects for the deep repository as an industrial establishment

Alternative	Prospects for establishment	Special advantages (+) and disadvantages (-)
Forsmark	Existing industrial area Existing harbour No overland transport outside industrial area Few landowners High nature protection values	+ Industrial area with nuclear activity + Low environmental impact - Site investigations in area with high natural values
Hargshamn	Existing industrial area or establishment of new one Existing harbour No, or short, overland transport outside of industrial area Few landowners	+ Good harbour - Uncertainty regarding possibility of establishment within existing industrial area
Tierp north/ Skutskär	Establishment of new industrial area in Tierp (forest land) Site not specified Harbour and parts of facility in Skutskär Overland transport, existing railway and new branch line Preliminary few landowners	+ Big area - flexibility + Harbour and industrial area in Skutskär - Overland transport - Establishment of new industrial area
Studsvik Björksund	Existing industrial area Existing harbour No overland transport outside of industrial area Few landowners	+ Industrial area with nuclear activity + Low environmental impact - Uncertainty regarding nature and culture protection interests - Uncertainty regarding land availability
Skavsta/ Fjällveden	Establishment of new industrial area in Skavsta (land intended for industry), plus small operating area (Fjällveden, site not specified) Harbour in Oxelösund Overland transport - existing railway and new branch line first-choice alternative to Oxelösund-Skavsta, tunnel Skavsta-Fjällveden Few landowners within Fjällveden area	+ Good harbour - Establishment of new industrial area and transport routes - Considerable environmental impact - Long distance between parts of facility
Simpevarp	Existing industrial area first-choice alternative No overland transport outside of industrial area Many landowners	+ Industrial area with nuclear activity + No transport of encapsulated spent fuel + Low environmental impact - Many landowners can be affected by site investigations
Oskarshamn south	Existing industrial area or establishment of new one Existing harbour No, or limited, overland transport outside of industrial area Relatively few landowners	+ Good harbour - Uncertainty regarding availability of existing industrial area
Hultsfred east	Establishment of new industrial area (forest land) Site not specified Existing harbour in Oskarshamn Overland transport, existing railway and new branch line Relatively few landowners	+ Big area - flexibility - Overland transport - Establishment of new industrial area

Forsmark

An establishment in Forsmark entails that the deep repository's surface facility is located on an industrial area with nuclear activity. The connection to the underground parts of the deep repository can take the form of a tunnel. An existing harbour can be used, and no overland transport is necessary outside of the industrial area.

Conclusion: The prospects for establishing the deep repository in Forsmark are deemed to be very good. The uncertainties that exist mainly pertain to the area's nature protection values.

Hargshamn

In the event of an establishment in Hargshamn, the deep repository's surface facility can be located either at the harbour or in an area west of highway 76. Suitable industrial land is available next to the harbour. The facilities above and below ground can then be connected via a tunnel. In the event of an establishment west of the highway, a new industrial area is required, plus overland transport a short distance from the harbour to the surface facility.

Conclusion: The prospects for establishing the deep repository in Hargshamn are deemed to be good. A siting of the surface portion at the harbour is preferable, since it involves the least intrusion. Such a layout might be prevented for environmental reasons and must be carefully considered before a site investigation is undertaken.

Tierp north/Skutskär

The area of geological interest is large, providing flexibility in the siting and layout of the deep repository's surface facility. Nearness to the East Coast Railway and the E4 motorway provide good connection possibilities for road and rail. Land areas, primarily forest land, need to be utilized for the construction of facilities and probably a rail connection. Rail transport of encapsulated fuel is required from a harbour, preferably Skutskär. An establishment requires the participation of the municipalities of both Tierp and Älvkarleby.

Conclusion: The prospects of establishing the deep repository's facilities in the Tierp north area, supplemented by facilities adjacent to the harbour in Skutskär, are deemed to be good, but associated with uncertainties.

Studsvik/Björksund

The repository's surface facility would in this case be situated at Studsvik. An existing harbour can be used and no overland transport is needed outside the industrial area. The facilities above and below ground can be connected by a tunnel, which must then pass some regional fracture zones. Within the Björksund area it may be suitable to establish a small operating area above the deep repository's underground facility.

Conclusion: The prospects for establishing the deep repository in Studsvik/Björksund are deemed to be good. Considerable uncertainties exist with regard to land availability. If the municipality's proposed new comprehensive plan is adopted, a large part of the Björksund area will no longer be available.

Skavsta/Fjällveden

An area at Skavsta intended for industrial activity has been deemed to be a suitable site for the deep repository's surface facility. In this case, transport would take place by rail, or possibly road, from the harbour in Oxelösund. New transport routes would have to be built, for the rail alternative probably a 4–5 km long branch line to the existing railway. The facilities above and below ground can be connected by a tunnel, which must pass some regional fracture zones and which will be approximately 15 kilometres long if the repository is located in Fjällveden. Such a long distance between the surface and underground parts of the repository could give rise to difficulties in organizing the operation of the deep repository in a rational manner. It may therefore be suitable to locate parts of the activities on the surface in an operating area established above the underground facility.

Conclusion: It is technically possible to establish the deep repository in Skavsta/Fjällveden, but the feasibility of the project is associated with considerable uncertainties. This is particularly true with regard to the possibilities of constructing new transport routes (road/rail/tunnel) and facilities, with the environmental impact this could cause.

Simpevarp

An establishment at Simpevarp provides great flexibility as regards system layout. As the first-choice alternative, the deep repository's surface facility is located inside the industrial area for nuclear activity on the Simpevarp Peninsula. The connection to the deep repository's underground portion can take the form of a tunnel. An existing harbour can be used and no overland transport is needed outside of the existing industrial area. If the deep repository's underground portion is built at a greater distance from the NPP's industrial area, it is suitable to establish an operating area above the underground facility's central area.

Conclusion: The prospects for establishing the deep repository in Simpevarp are deemed to be very good and the uncertainties small. In terms of transport, the alternative offers unique advantages.

Oskarshamn south

This siting alternative is based on utilizing the harbour in Oskarshamn. One possibility is to locate the repository's surface facility in the harbour's industrial area as well, from which a tunnel is built connecting to the underground repository. However, the availability of land within the harbour area is uncertain. Another possibility is to locate the facility in an industrial area established at Storskogen, or above the deep repository underground facility. Transport from the harbour can then take place by rail.

Conclusion: The prospects for establishing the deep repository in the southern part of Oskarshamn Municipality are deemed to be good, but there are uncertainties, mainly regarding the availability of land in the harbour area and a suitable system layout.

Hultsfred east

In the event of an establishment in Hultsfred, the deep repository's surface facility is located in an industrial area that is built within the geologically interesting area. No site can be designated. The area is large and there is considerable flexibility. Transport in the main alternative is by sea to Oskarshamn, and further on an existing railway from which a new branch line is built to the site of the deep repository.

Conclusion: The prospects for establishing the deep repository in Hultsfred are deemed to be good, but there are uncertainties, mainly regarding the transport question and the location of the surface facility.

SKB's conclusion

As far as environmental impact is concerned, SKB concludes that the establishment and operation of the deep repository can be arranged and conducted in an environmentally acceptable way for all alternatives. This judgement is based on the fact that the activities generally cause little environmental impact compared with other industrial activities of equivalent size, and that the deep repository's surface facilities can be located at a relatively great distance (several kilometres) from the underground facilities. This last factor permits the location of the repository to be determined by the properties of the bedrock, while the location of the surface facilities can be determined by the requirements on least intrusion and detriment.

Figure 12-2 shows the parts included in the handling chain from the encapsulation plant to the deep repository for the different siting alternatives. An establishment at Simpevarp offers the shortest and simplest handling chain, since the encapsulated fuel can be driven directly from the encapsulation plant to the deep repository without transshipment. In the other alternatives, transshipment and sea transport are required, and in three cases overland transport as well. The siting alternatives that involve overland transport require laying of new railway and utilization of new land for industrial purposes.

SKB concludes that a siting in areas where nuclear activities already exist is advantageous, since infrastructure that suits the needs of the deep repository already exists there. In SKB's judgement there are two alternatives that offer obvious advantages. These are Forsmark and Simpevarp, both of which have harbours, available industrial land, and nuclear activities. SKB finds that this offers particularly good prospects of satisfying the requirements of the Environmental Code that industrial sitings shall take place so that the purpose is achieved with the least possible intrusion and detriment. Overland transport of spent nuclear fuel on public roads/railways is avoided with these alternatives.

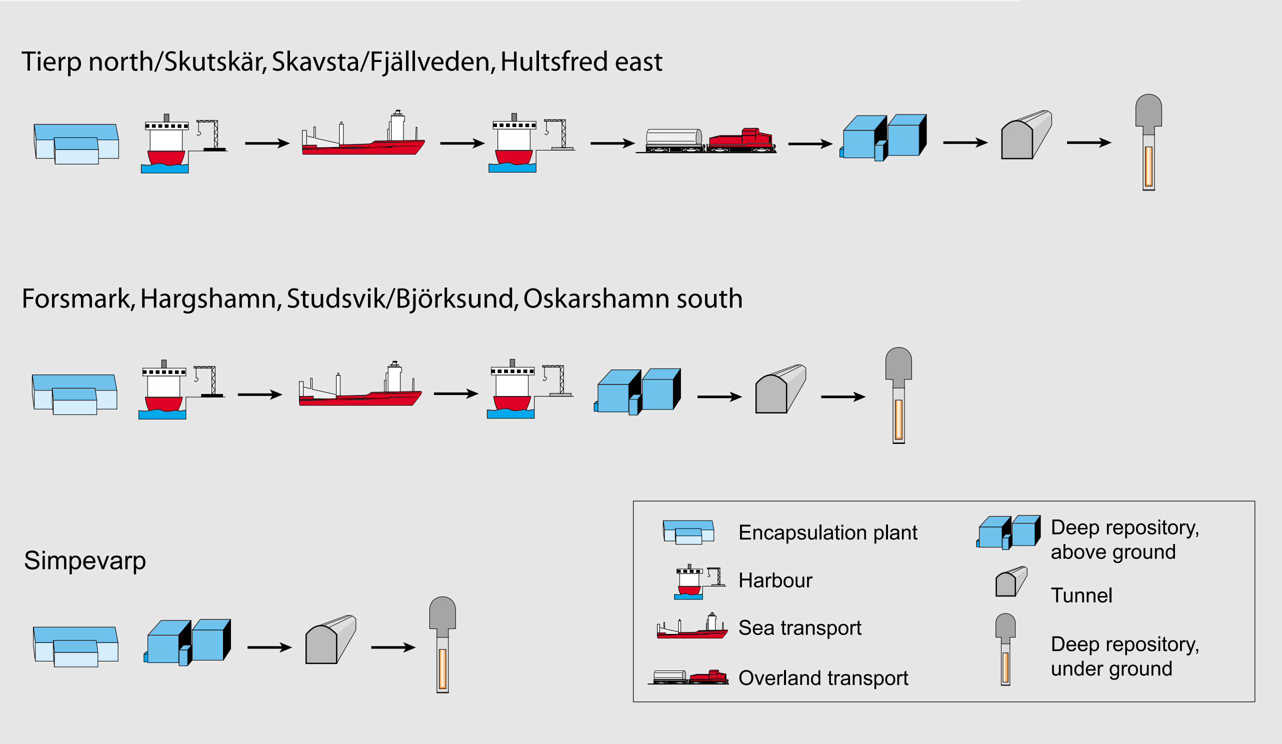


Figure 12-2. *Parts of the system for handling of the encapsulated fuel from the encapsulation plant to the deep repository for the different siting alternatives. The encapsulation plant could also be located at the deep repository. The handling chain would then begin at CLAB.*

In the case of the other alternatives, the prospects for establishment of the deep repository are deemed to be comparable, except for Fjällveden and Björksund, where the uncertainties are deemed to be greater than for the other alternatives. The intrusion that would be entailed by the construction of new infrastructure reduces the prospects of implementing an establishment in Fjällveden. As far as Björksund is considered, there are uncertainties as to whether land will be available.

12.3.3 Societal aspects

The societal prerequisites that must be satisfied if establishment of a deep repository is to be possible are presented in section 10.4. Of the factors described, the one that must weigh most heavily in the choice of a site in SKB's opinion is confidence on the local level. The participation of concerned municipalities in the siting process shall be voluntary.

Local confidence in the deep repository establishment is important

An important factor is the attitude of those affected by the establishment and operation of the deep repository's facilities and transportation system. When it comes to transportation, neither sea nor overland transport of radioactive material is considered to be an appreciable risk factor from a safety or technical viewpoint. Overland shipments of spent nuclear fuel on public transport routes are rare in Sweden, however, making it difficult to judge their feasibility from a public opinion viewpoint. Due to uncertainty on this point, SKB considers the need for overland transport to be a disadvantage.

With these general judgements as a point of departure, the following evaluations are made of the different siting alternatives:

Forsmark

Since existing industrial land can be used, only a few people will be directly affected. Nearby residents at Forsmark have been informed that test drilling may be done in the area. SKB has perceived support for these plans from the majority of the nearby residents. There is an opposition group in the municipality.

Hargshamn

As in the case of Forsmark, SKB sees generally good prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository in Hargshamn. At the same time, SKB observes that a repository in Hargshamn has not been discussed seriously, since Forsmark is locally perceived to be a natural first choice.

Tierp north/Skutskär

An establishment in Tierp entails transport of spent nuclear fuel by rail, as a main alternative from the harbour in Skutskär. Other transport alternatives entail longer transport distances. The feasibility study has created great interest among elected officials and the public in the municipalities. There is an active opposition group.

SKB concludes that there are good prospects for obtaining the support needed for establishment. However, since neither the site for the deep repository nor transport solutions have been defined, uncertainties remain which are difficult to assess.

Studsvik/Björksund

In contrast to other feasibility study municipalities, the municipal council in Nyköping has not made any decisions regarding the feasibility study. Opinion polls point towards support among the public for moving ahead with site investigations. There are opposition groups who are propagating against further siting studies and a possible repository establishment.

During the feasibility study, clear criticism was levelled at the Studsvik/Björksund alternative. There is an organized resistance group in Tystberga. Critical viewpoints have been proffered by the county administrative board and the Nature Conservation Society. With reference to strong nature protection interests in the vicinity of Studsvik, these bodies consider the coastal area to be too sensitive to permit the kind of industrial activities a deep repository would entail.

If the municipality's proposed comprehensive plan is adopted, it would impose restrictions on certain types of facilities, including nuclear activities, within a large part of the Björksund area. In the light of this, SKB does not find it worthwhile to carry on with the studies of the Studsvik/Björksund alternative.

Skavsta/Fjällveden

The Skavsta/Fjällveden alternative has been proposed after circulation of the preliminary final report from the feasibility study for comment. It is therefore difficult to get a clear picture of attitudes towards this alternative. An establishment would entail the construction of new transport routes and facilities, and in the operating phase shipments of spent nuclear fuel would have to go through two cities. Against this background, SKB judges that there are considerable uncertainties that make it difficult to obtain the necessary support for siting at Skavsta/Fjällveden.

Simpevarp

An establishment at Simpevarp would probably entail locating the deep repository's surface facility in an existing industrial area. Locating the underground facility west of the Simpevarp Peninsula would involve relatively many landowners. Otherwise only a few people would be affected by an establishment.

SKB believes there are good prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository at Simpevarp. Due to the nuclear power plant and CLAB, nuclear activities in the locality are by tradition strongly associated with Simpevarp, making this site a natural first choice for a deep repository as well in many people's view.

Oskarshamn south

SKB generally considers the prospects of obtaining the necessary support from elected officials, nearby residents and the public for establishing a deep repository south of Oskarshamn to be good. At the same time, we make the judgement that a repository in the area has not been discussed seriously, since most parties view Simpevarp as a natural first choice.

Hultsfred east

An establishment in Hultsfred involves transport of spent nuclear fuel, probably from the harbour in Oskarshamn, and would then affect four municipalities – Oskarshamn, Mönsterås (marginally), Högsby and Hultsfred.

SKB considers that there are good prospects of obtaining support for a deep repository establishment. The uncertainties are judged mainly to apply to the transport question and the objections that may exist locally to any alternative that entails nuclear waste management on any other site in the region than the current one, i.e. Simpevarp.

SKB's conclusion

SKB concludes that for all feasibility studies included in the selection pool, there is support among elected officials and the public that provides good prospects for proceeding with site investigations. This judgement is based on e.g. the opinion surveys that have been conducted for SKB's account.

SKB considers that the siting alternatives can be ranked with respect to societal prospects, insofar as Simpevarp and Forsmark offer better prospects than the others. One reason for this is that confidence in SKB's activities is deemed to be most stable in those localities where nuclear activities have long existed. Stable local confidence, gained by practical action, is seen as a positive factor that can strengthen the prospects of implementing the deep repository project in both the short and long term.

Further, SKB concludes that a siting of the deep repository in Forsmark or Simpevarp is regarded by many as a natural choice. A common argument for this is that provided that the safety requirements can be satisfied, and that the bodies whose job it is to determine this can be relied on, it is difficult to see any rational arguments for other choices than the sites where nuclear installations are already located. An exception is Studsvik/Björksund, where several reviewing bodies have offered critical viewpoints.

Other siting alternatives entail establishment in localities that do not have any nuclear activities. SKB's opinion is that this requires prolonged discussion in the municipality in question and among nearby residents to determine their attitude to such an activity. Against the background of results from opinion surveys and the interest shown by elected officials and the public during the feasibility studies, SKB believes there is sufficient support to proceed with site investigations. The municipality and other stakeholders will not have to make a decision on an establishment for another eight years or so, which means there is plenty of time for them to look deeply into the matter.

12.4 SKB's choice of sites

In the preceding sections, SKB has presented its evaluation of the prospects for realizing an establishment of the deep repository for the siting alternatives arrived at in the feasibility studies. Separate evaluations have been made of the prospects and uncertainties regarding the bedrock, the industrial establishment and support from society. The conclusions SKB has drawn from the evaluation are as follows:

- Bedrock with good prospects of meeting the safety requirements exists for all siting alternatives. In most cases, however, knowledge is lacking of conditions at repository depth, which means that there are no grounds for ranking the alternatives at the present time. The lack of data from repository depth means that there is a risk that test drilling will reveal such conditions that a site must be abandoned.
- The possibility of establishing the deep repository's industrial operation and transportation is important, but subordinate to the importance of the properties of the bedrock. A siting at Simpevarp or Forsmark is judged to offer particularly good prospects of satisfying the requirement of least intrusion and detriment. Infrastructure adapted to the needs of the deep repository also exists at these sites. The siting alternatives of Hargshamn, Tierp north, Oskarshamn south and Hultsfred east are also judged to offer good prospects.
- The prospects of achieving the confidence and support in society and the local community that are needed for implementation of the deep repository project are difficult to judge and may change. Opinion surveys show that good support exists for site investigations in all feasibility study municipalities. This support is judged to be most stable in the cases of Forsmark and Simpevarp.

SKB's goal is to be able after the site investigations to identify a site that satisfies all requirements on a deep repository establishment. The choice of sites for site investigations must be made in the light of this overall goal. This means that the programme must be so robust that negative results from test drilling or changed premises for the siting programme can be handled without jeopardizing the overall goal.

SKB concludes that Forsmark and Simpevarp have clear advantages from an establishment and societal viewpoint. They have a good prognosis when it comes to the bedrock as well. With these advantages, it is difficult to see any reason why not to proceed with these alternatives. SKB's conclusion is thus that these two alternatives must be included in the next phase.

In order for the programme to be robust, SKB deems that the continued siting studies should include more alternatives than the two mentioned above. The next phase should therefore include studies of alternatives that have good prospects, but are different from Forsmark and Simpevarp. Additional sites should mainly represent other geological conditions and be located in other municipalities.

Of the siting alternatives, Tierp north and Fjällveden can contribute towards broadening the geological range of alternatives. These sites should therefore be included among the alternatives that are studied further, in SKB's opinion. Tierp north, together with Skutskär, offers good industrial establishment possibilities. SKB judges this alternative to be fully realistic from all aspects. There is a greater degree of uncertainty for Fjällveden with regard to feasibility.

Other siting alternatives do not offer any obvious advantages from the geological breadth aspect. However, there is not good reason at this point to either dismiss or commence site investigations for any of these alternatives. Hargshamn is the leading alternative if it should not be possible to commence site investigations in Forsmark or if the investigations show that the bedrock does not meet the requirements. Similarly, Oskarshamn south and Hultsfred constitute possible alternatives to Simpevarp.

SKB's opinion is that a choice of Forsmark, Simpevarp and Tierp north for test drilling and further study, along with additional studies of the prospects for the Skavsta/Fjällveden alternative (see Figure 12-3), offers a reasonable balance between the preference of a focused but robust programme on the one hand and a reasonable level of cost and effort on the part of society on the other.

Against the background of the above evaluations and the current state of knowledge, SKB thereby prioritizes site investigations with test drilling at the following three sites:

- **Forsmark in the municipality of Östhammar**
  The priority area is well-defined and it should be possible to commence site investigations with test drilling shortly after a decision to proceed.
- **Simpevarp in the municipality of Oskarshamn**
  Large areas with potentially suitable bedrock exist west of Simpevarp, but the area nearest the nuclear power plant is prioritized. Here SKB also intends to investigate the prospects for a siting of the deep repository's underground facility on the Simpevarp Peninsula, despite the fact that this area is not prioritized from a geological viewpoint. SKB deems it worthwhile to investigate whether the bedrock meets the requirements in view of the fact that an establishment of the entire facility within the existing industrial area would cause the least detriment. It should be possible to commence site investigations with test drilling shortly after a decision to proceed.

- **Tierp north/Skutskär**
  The priority area north of Tierp is relatively large, so that initial efforts must be focused on defining a priority subarea for continued investigations and studying a suitable layout of the deep repository's surface facility and transportation system. After that, SKB intends to initiate test drilling within the priority subarea. This alternative requires the continued participation of the municipalities of both Tierp and Älvkarleby.

The greatest uncertainties for Skavsta/Fjällveden in the municipality of Nyköping are associated with industrial establishment and transportation. SKB therefore plans to proceed primarily with studies of these questions in order to clarify the feasibility of the alternative. As regards the bedrock in the area of interest, data are already available from repository depth. SKB intends to utilize these data to conduct a new safety assessment with the modern methodology used in the SR 97 safety assessment. Test drilling in Nyköping will only be considered if the first three alternatives mentioned above fail to live up to expectations.

Preliminary programmes for the siting alternatives chosen for further study are presented in Chapter 14.

If any additional alternatives should be considered, a discussion will be initiated with the concerned municipality and the regulatory authorities. A clear decision by the municipality supporting such a change of the programme is required before any investigations are commenced on a new site.

The municipality and other stakeholders will not have to make a decision on a siting application for the deep repository for another eight years or so. Until that time, studies and investigations of bedrock, technology, environment and societal aspects will be conducted in order to gather the background material that is required to make a final judgement of the siting prospects.

Forsmark

Site investigation with test drilling

Determine layout of facilities

Simpevarp

Site investigation with test drilling

Determine layout of facilities

Tierp north/ Skutskär

Site investigation with test drilling, but first a drilling area must be chosen

Determine layout of facilities and transport solutions

Skavsta/Fjällveden

Study establishment prospects and transport options

Conduct safety assessment

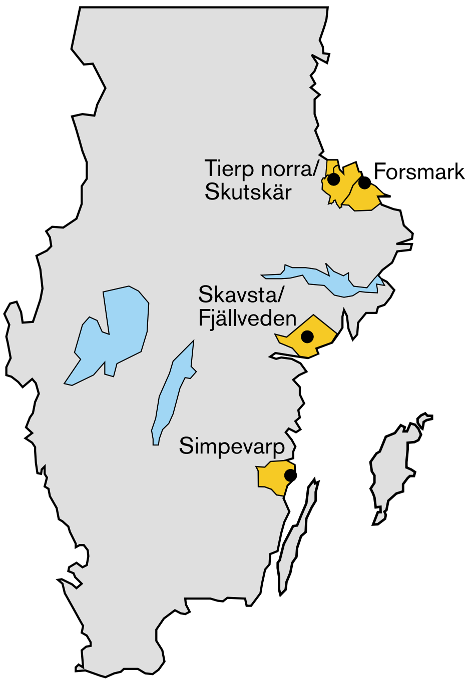


***Figure 12-3.** Siting alternatives prioritized by SKB for further studies.*

Part IV - Programme

13 Site investigation phase

The goal of the site investigation phase is to obtain permits to site and build the deep repository and the encapsulation plant. Siting investigations for these facilities shall be accompanied by environmental impact statements (EISs). Dialogue and consultations with concerned parties have from the start been an important part of the siting work. When the work proceeds to site investigations, consultation in accordance with the provisions of the Environmental Code can be commenced.

In a site investigation, a large quantity of data on the bedrock are collected and evaluated. These data are needed to assess the long-term safety of a repository for spent nuclear fuel on the investigated site. The data are also needed to describe how the deep repository's facilities above and below ground can be configured and built in consideration of the bedrock and infrastructure. The programme further provides the background material needed to judge what impact a repository will have on the environment during construction and operation.

This chapter provides a general description of the programme for the site investigation phase. Chapter 14 describes how the programme is applied in the different regions.

13.1 Goal and scope

The goal of the site investigation phase is:

- To obtain a permit to site and build the deep repository for spent nuclear fuel.
- To obtain a permit to site and build the encapsulation plant.
- To clarify how canister fabrication and transportation are to be arranged.

The site investigation phase includes:
- test drilling
- safety assessment
- facility design
- transport studies
- environmental impact assessment
- consultations

The permit applications are based on broad supporting documentation. For the deep repository, investigations of the rock are required to determine whether it is possible to build the repository on any of the proposed sites and to conduct a safety assessment. It is these investigations that have given the site investigation phase its name, since they dominate the activities during this phase. The investigations of the rock serve as a basis for configuring the underground parts of the deep repository, but will also influence the positioning and layout of the surface parts of the repository.

Another important part of the work is to study and propose a local layout and positioning of all buildings and functions, plus associated transportation system and other infrastructure. As a part of this work, concerned land areas will be investigated and the impact of the facilities on the environment and on society will be studied. In parallel with the study work, consultations will be held with county administrative boards, regulatory authorities and municipalities, as well as with members of the public and organizations that can be expected to be affected, in keeping with the requirements and intentions of the Environmental Code. When the study results have been compiled, SKB will submit permit applications for the encapsulation plant and the deep repository. Figure 13-1 illustrates schematically the various activities included in the site investigation phase for the deep repository and the encapsulation plant.

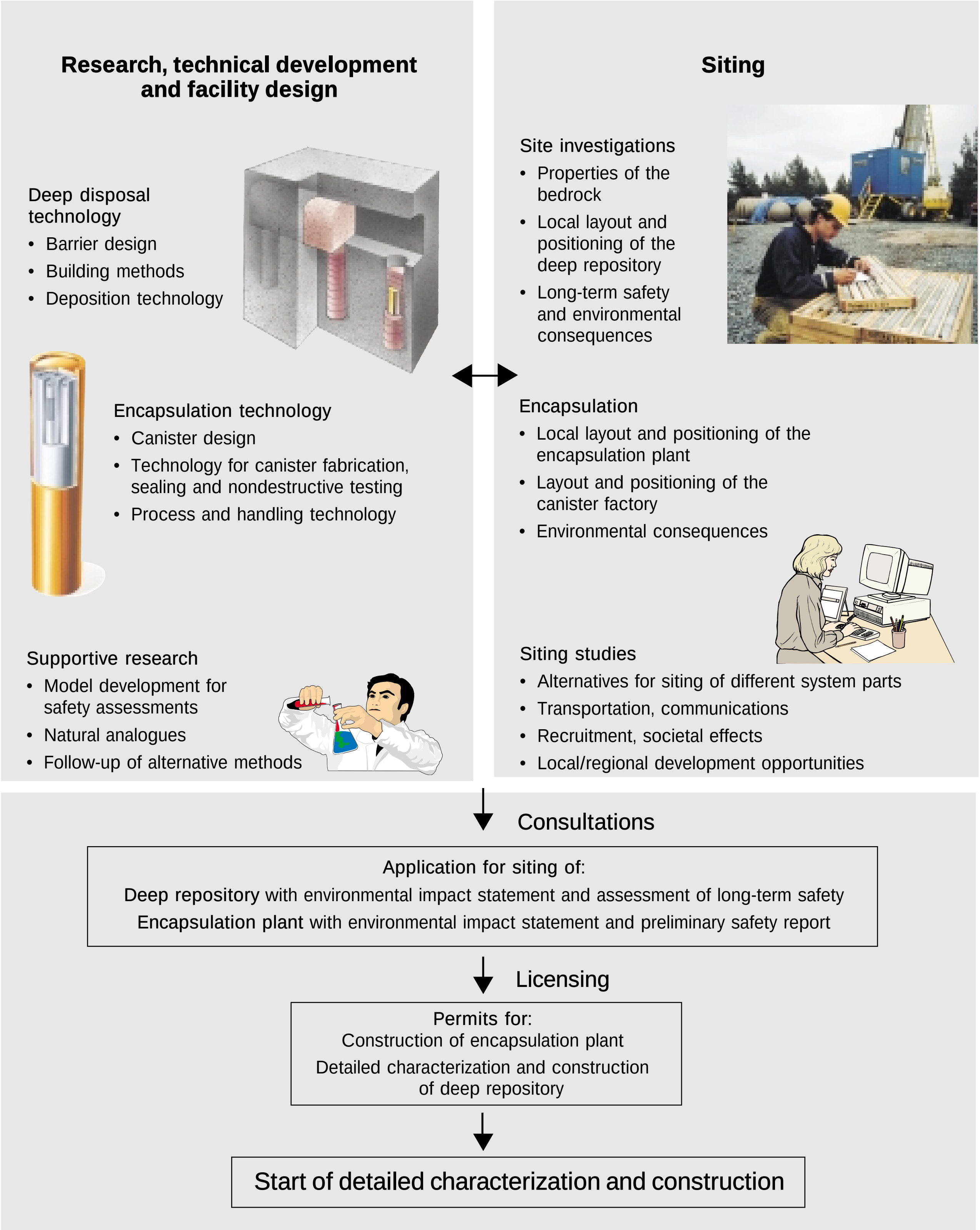


Figure 13-1. *Main components in the siting work for the deep repository and the encapsulation plant during the site investigation phase.*

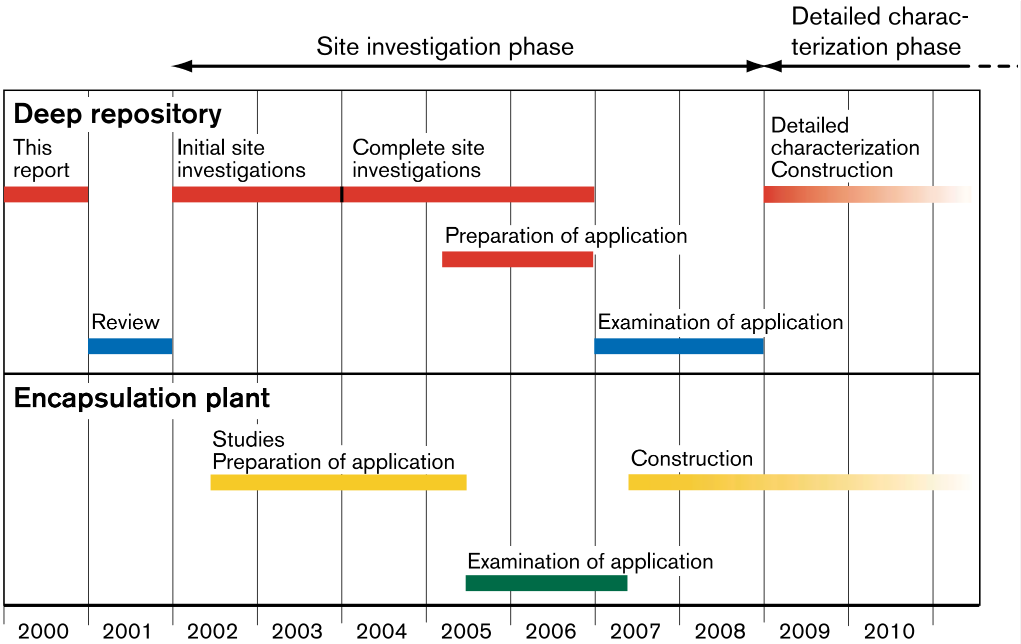


***Figure 13-2.** General timetable for the site investigation phase showing the most important milestones.*

Timetable for the site investigation phase

Figure 13-2 shows a general timetable for the site investigation phase. SKB is planning to commence the site investigations for the deep repository during 2002, and expects to have supporting material and applications for the deep repository ready 5–6 years later.

SKB wants to initiate site investigations in 2002

A large body of documentation already exists for the encapsulation plant. It is estimated that an application for the encapsulation plant can be ready and the licensing process can be initiated a year or so before the equivalent application for the deep repository.

The applications will mainly be examined under the Nuclear Activities Act, the Environmental Code and the Planning and Building Act. The preparation of the licensing matters performed by SKI pursuant to the Nuclear Activities Act is of central importance. Licensing (examination of permit applications) and permissibility assessment will be done primarily by the Government, the Environmental Court and the municipality. The time required for preparation and examination of each application is estimated to be around two years.

It is also appropriate to apply for the necessary permits for important parts of the transportation system, such as build-out of railways and harbours.

The time needed to obtain a permit and build a canister factory is estimated to be considerably shorter than for the deep repository and the encapsulation plant, so the application for this plant can be submitted later.

13.2 Licensing and EIA work

13.2.1 Licensing

Permits under the Nuclear Activities Act are examined by the Government after the matter has been prepared by SKI. The Government shall also assess the permissibility of nuclear activities in accordance with Chapter 17 of the Environmental Code after preparation by the Environmental Court. If the Government declares the construction of the facility (encapsulation plant or deep repository) permissible under the Environmental Code and issues a permit under the Nuclear Activities Act, it remains for the Environmental Court to issue a permit and stipulate conditions under the Environmental Code.

SKI's and SSI's communication regarding EIA in the final repository question /13-1/, statements in the *travaux preparatoires* to the Environmental Code and the consequential legislation bill (1999/98:90) provide good guidance regarding the procedure to be followed for licensing of a final repository for spent nuclear fuel. Inasmuch as the same matter is to be examined by several bodies, co-ordination is appropriate. Since the Environmental Court, in connection with examination under the Environmental Code, may not issue a permit until the Government has declared the activity permissible, the proceedings at SKI and the Environmental Court should be conducted so that the Government can make decisions under both laws at the same time. This means that SKI and the Environmental Court must coordinate the permissibility proceedings so that both can give their statements to the Government at roughly the same time. The *travaux preparatoires* to the Environmental Code state that both the Environmental Court and the concerned municipality should have access to SKI's and SSI's assessments and reviews regarding examination under the Nuclear Activities Act in their treatment of the permissibility assessment under the Environmental Code.

The municipality's planning and examination under the Planning and Building Act should be able to take place in parallel with the regulatory examination process. Here it would be desirable if the municipality had prepared the way for processing of the building permit application by comprehensive planning supplemented with a detailed development plan or area regulations.

When SKB has obtained the requisite permits, construction of the encapsulation plant and detailed characterization of the deep repository site, and thereby also in practice construction of the deep repository, can begin.

The canister factory is a conventional industrial plant that does not contain any nuclear activity. Licensing is thereby considerably simpler, partly because there is no permit examination under the Nuclear Activities Act, and partly because permissibility assessment by the Government under Chapter 17 of the Environmental Code is not required. All that remains then is examination by the Environmental Court and the municipality under the Environmental Code and the Planning and Building Act.

13.2.2 Environmental impact assessment and consultations

Early consultation

Done so that SKB will obtain viewpoints from the county administrative board and private individuals who may be particularly affected

Extended consultation

Also includes other national authorities and the municipalities, private individuals and organizations that can be expected to be affected

Ever since the siting work was commenced in 1992, SKB has consulted in various forms with e.g. regulatory authorities and concerned municipalities. In accordance with the Government's decision regarding RD&D-Programme 98, special efforts have been made to "...consult with concerned municipalities, county administrative boards and regulatory authorities". In conjunction with the commencement of site investigations with deep drilling, SKB intends to formally notify the deep repository matter to the county administrative board for consultation in accordance with the provisions of the Environmental Code. Early consultation shall be held with the county administrative board and with private individuals who are particularly affected by the planned activity. In the case of a nuclear installation, the early consultation is followed by extended consultation, which includes concerned authorities, municipalities, members of the general public and organizations. This extended consultation shall relate to the siting, scope, design and environmental impact of the activity or measure, as well as the content and design of the environmental impact statement. The consultation will continue throughout the site investigation phase. SKB's goal is that it should result in a carefully prepared and solidly underpinned environmental impact statement as a supporting document for a decision in the encapsulation plant and deep repository permit matters. Following is a more detailed account of the planned design of the consultations. Previously held consultations are described in the Appendix, with a focus on the consultation SKB has had during the preparation of the present report.

Consultation prior to the start of site investigations

This report will be reviewed by SKI and circulated for comment. In conjunction therewith, SKI plans to hold public hearings in those municipalities that are proposed for site investigation. When SKI has finished its circulation for comment and review of SKB's integrated account and "the Inspectorate deems that the accounts are complete, the Inspectorate will hand them over to the Government so that the necessary decisions can be made". In the event of a Government decision in SKB's favour, the municipalities being considered for site investigations will then decide whether they wish to continue participating in the siting process. The decisions of the municipalities are expected to come towards the end of 2001.

Site investigations do not require permits according to the Environmental Code

Site investigations do not in themselves require a permit and are not expected to lead to any appreciable disturbances of interests worthy of protection. However, the activities must be notified to concerned county administrative boards in accordance with Chapter 12 of the Environmental Code in the case of activities not requiring a permit and to the municipality. Notification to both the municipality and the county administrative board will be accompanied by a description of the activities entailed by the site investigation, their design and scope, possible intrusions into the surrounding environment, and the protective measures SKB plans to adopt. A quality and monitoring programme will exist to verify fulfilment of the company's obligations. SKB intends to conclude agreements with the landowners regarding the investigation activities.

SKB will prepare locally adapted programmes for the site investigation phase and design the programme in consultation with municipalities, regulatory authorities and other concerned parties so that disturbances are limited (see Chapter 14).

Consultation prior to application for a siting permit for the deep repository

SKB sends notification to the county administrative board

When the site investigations are commenced, the matter of the establishment of the deep repository for spent nuclear fuel will be notified to concerned county administrative boards in accordance with the provisions of the Environmental Code. With this, SKB will initiate an early consultation in accordance with Chapter 6 of the Code with the county administrative board and the members of the public who are expected to be particularly affected by a future deep repository in any of the relevant municipalities. The consultation work that is already in progress will then become statutory consultation procedures in the sense of the Environmental Code. In a similar manner, notification will be made for the encapsulation plant to the county administrative board in Kalmar County, since the main alternative is a siting at CLAB. On the other sites where consultations will be held concerning a possible deep repository, the alternative of a siting of the encapsulation plant adjacent to the deep repository will also be discussed as a part of these consultations. The views of the county administrative boards in the relevant counties on the consultation questions are presented in a recently published memorandum /13-2/. The EIA forum in Kalmar County has prepared a report on delimitations of questions prior to the site investigation phase as a basis for discussion with nearby residents, the public and neighbouring municipalities /13-3/.

The county administrative board decides on extended consultation

When the county administrative boards have made their decisions on extended consultation, SKB will also consult with the central authorities on what requirements they have on an EIA. Then extended consultation will also be started with the county administrative board, "particularly affected" persons (landowners, nearby residents and others who may be directly affected by an establishment near them), concerned municipalities, regulatory authorities, environmental and nature conservancy organizations, all in accordance with the statutory comment on Chapter 6, Section 5 of the Environmental Code /13-4/. SKB will also take into account the Swedish Environmental Protection Agency's general recommendations on environmental impact assessments pursuant to the Environmental Code /13-5/, which provide good guidance on how the various steps of the coming EIA work can be conducted. These recommendations are currently being circulated for comment.

Extended consultation is expected to continue until the site investigations have been concluded and the results evaluated. The work shall result in an EIS (environmental impact statement), which shall be submitted as a supporting document with the permit application.

In RD&D-Programme 98, SKB presented a proposal for the contents of an EIS. It should identify and describe direct and indirect effects which the planned activities at the deep repository may have on man and the environment as well as on natural resource management. Within the framework of the statutory consultations with concerned members of the public, the municipality and regulatory authorities, a more detailed description of the contents will gradually emerge from the discussions which SKB has with the various consultation parties. Through these consultations, different stakeholders can influence the design of the planned activities, for example how rock spoils are to be handled or how roads are to be routed. Assessments concerning the contents and scope of an EIS will be central issues to discuss during these consultations. Within the framework of the consultations, SKB will also make regular reports on the progress of the work with investigations, evaluations, safety assessment and facility design.

In a similar manner, an EIS will be prepared for the encapsulation plant to be submitted as a supporting document with an application for a permit to site and build this plant.

13.3 Geoscientific site investigations

- General programme
- Discipline-specific programmes
- Site-specific programmes

In its decision on RD&D-Programme 98 /13-6/, the Government has required that SKB present a clear programme for site investigations before site investigations are commenced. Such a programme has been prepared /13-7/ based on SKB's experience of rock investigations, described in Chapter 9.

The programme describes the scope of the geoscientific information which SKB intends to collect on a site and how the information is to be used in evaluating the suitability of the site for a deep repository. The programme is general and based on the assumption that the deep repository will be built on the investigated site. The general programme will be supplemented in early 2001 by more detailed descriptions, so-called discipline-specific investigation programmes, which give an account of what investigation methods and what measurement equipment will be used in various stages of the site investigations.

The investigations also include inventory and oversight of the site's natural and cultural values. An inventory is taken at an early stage so that the site-specific programmes can be planned to minimize the impact of the investigations on sensitive natural and cultural values. This is then followed up during the execution of the investigations.

Site-specific programmes will be prepared during 2001 for the areas that have been proposed for site investigations. These programmes are based on the general programme but adapted to specific conditions prevailing on the site in question (see Chapter 14). Examples of factors that govern the design of these programmes are the size of the area of interest, the degree of detail and reliability to which the geoscientific conditions are known, what specific geological questions exist, available infrastructure, and culture and nature conservation interests. In designing the programmes, consultation will take place with landowners, nearby residents, the municipality, the county administrative board and other concerned stakeholders for the purpose of limiting disturbances of land and environment due to the investigation activities.

13.3.1 General programme for investigation and evaluation

The geoscientific work is supposed to provide the broad knowledge base that is required to achieve the overall goals of the site investigation phase presented in section 13.1. The knowledge will be utilized to evaluate the suitability of investigated sites for the deep repository and must be comprehensive enough to:

- Show whether the selected site satisfies requirements on safety and technical aspects.
- Serve as a basis for adaptation of the deep repository to the characteristics of the site with an acceptable impact on society and the environment.
- Permit comparisons with other investigated sites.

Activities and main reports

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

- Site description
- Facility description
- Safety report

Besides preparation of these reports, a continuous transfer of data takes place from investigations and design to the EIA work.

The site description presents all collected data and model results that are of importance for the overall scientific understanding of the site, as well as for design and safety assessment. The site description should furthermore describe current states and naturally ongoing processes on the site and in its environs. Geoscientific models and models of the ecosystem are devised for this purpose.

The facility description presents the repository's configuration and possible layout alternatives based on data from the investigations. The positioning of facility parts above ground, as well as site-specific preconditions for the rock work to be done – such as requirements on rock reinforcement, sealing requirements or choice of backfill material – are also described. A technical risk evaluation is carried out, including a description of uncertainties in calculations and the environmental impact of the civil engineering work. The facility description includes the choice of technology, underground repository layout, and positioning of facility parts above ground, as well as how rock spoils are to be handled.

The safety report shows how long-term safety is ensured for the planned deep repository based on investigation results and repository layout. The safety assessment obtains data from the other principal activities and then performs analyses of thermal, hydraulic, mechanical and chemical processes around the deep repository, as well as calculations of radionuclide transport. The results of various analyses can, for example, be used as a basis for choices between alternative repository layouts or for choice of backfill material. Data should serve as a basis for an assessment of at least the same scope as the SR 97 safety assessment.

Geoscientific model
Description of the properties of the bedrock and the groundwater

Repository layout
Positioning of the repository's underground parts such as deposition areas, central area and access tunnels, see Chapter 6

Thermal processes
How heat spreads

Hydraulic processes
How the groundwater moves

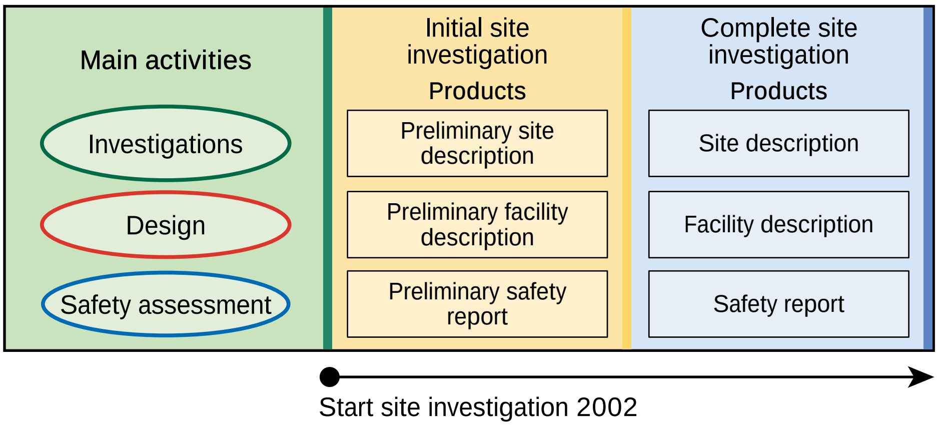


Figure 13-3. *Activities and main reports during the site investigations. The reports comprise part of the supporting documentation to be submitted with the application for a siting permit for the deep repository.*

As is illustrated in Figure 13-3, preliminary versions of the aforementioned main reports are prepared at an early stage and subsequently updated, expanded and modified to obtain the final documents.

The investigations are supposed to provide data on the biosphere and geosphere on the site as a basis for site-adapting the deep repository and assessing its long-term performance and radiological safety. The investigations include the following steps: inventory, planning, field work, interpretation, documentation and archiving. The choice of parameters that need to be determined is based on SKB's experience of investigations of rock, including the Äspö HRL, and from various performance and safety assessments that have been conducted. The data need has been cross-checked against experience and conclusions from SKB's most recent safety assessment, SR 97 /13-8/. The investigation methods and the parameters that can be determined are described in the geoscientific site investigation programme /13-7/.

The design process is supposed to adapt the layout of the facilities above and below ground, the transport solutions, technical supply systems etc. to local conditions. The point of departure is the reference design of the system presented in the system analysis /13-9/. The work involves both design of facilities and systems and planning of the activities during the construction and operating phases. There is a freedom in the distribution of functions between facility parts and the positioning of these parts in relation to each other. Except for its dependency on the rock data which the site investigations are supposed to provide, the process of designing the deep repository does not differ appreciably from the technical planning for other industrial establishments.

A continuous and comprehensive exchange of information takes place between investigations, design and safety assessment. The solid arrows in Figure 13-4 symbolize the paths of information exchange, where the results from investigations and design serve as a basis for the safety assessment. The dashed arrows in the figure symbolize the need for feedback from design and safety assessment to investigations. In the middle of the figure is the important coordination function which sees to it that an overall evaluation is made of the prospects of the site and provides coordination between different principal activities and different sites. The last-named point is important for a rational allocation of investigation resources, but above all for enabling the sites after completed investigations to be compared in an application for a permit to site the deep repository at one of the investigated sites.

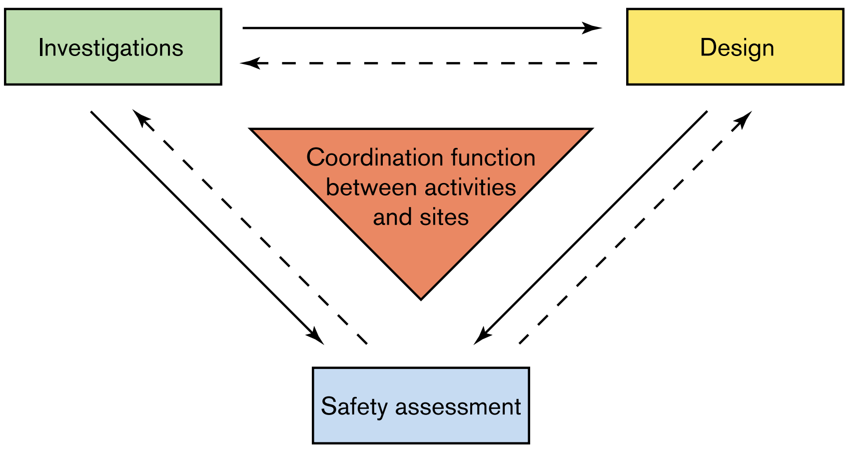


Figure 13-4. *Illustration of the information exchange between the principal activities investigations, design and safety assessment. In the middle of the figure is a coordination function which is responsible for the overall evaluation of the site and coordination between different principal activities and different sites.*

Initial site investigations

The site investigation phase is of such a large scope in terms of time, space and content that it must be subdivided into stages to permit a rational execution of all investigations and analyses, see Figure 13-5. Dividing the work into stages also makes it easier to adapt the investigation methods to conditions on the site and to give feedback to site evaluation.

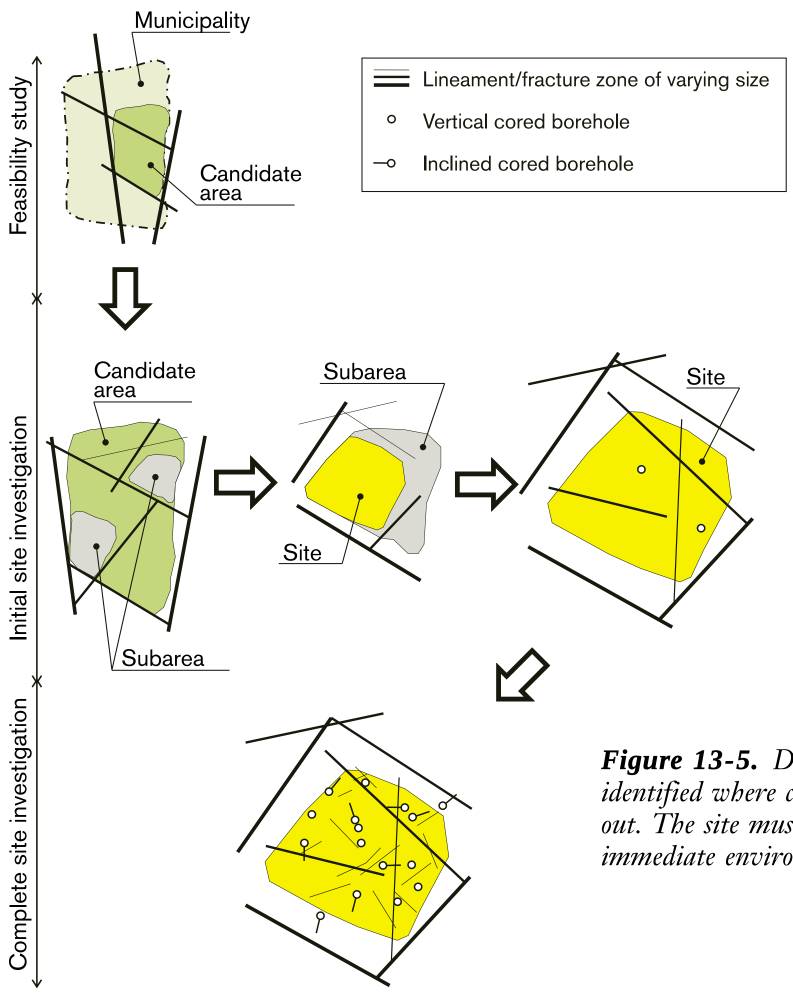


Figure 13-5. *During the initial site investigation, a site is identified where complete site investigation is then carried out. The site must accommodate a deep repository and its immediate environs with good margin.*

The first stage of the site investigations is called initial site investigation. The main goals for this stage are:

- To identify and select the site within a specified candidate area that is deemed to be most suitable for a deep repository and thereby also the part of the area to which further investigations will be concentrated, and
- To determine, with limited efforts, whether the feasibility study's judgement of the suitability of the site holds up in the light of in-depth data.

By "site" is meant here a prioritized part of a candidate area. The site must be large enough to accommodate the deep repository and its immediate environs, roughly 5–10 square kilometres, with good margin.

Geological mapping
Mapping of rocks and fractures

The point of departure for site investigations is different for the different identified siting alternatives. The identified areas are of different size, there are differences in the geoscientific knowledge base, and site-specific questions are of great importance. The initial investigations will be adapted to these site-specific factors. Site-specific programmes will be devised, see Chapter 14, and the following presentation should therefore be regarded as one possible execution of an initial site investigation.

Ground radar
Used to map soil layers, groundwater table and overburden thickness

The investigations are based on the feasibility studies' account of the bedrock and biosphere in the candidate area, which was in turn based on existing information and augmented with limited field studies. In order to be able to identify and select a suitable site within the area, the investigations are begun with a general geological mapping and geophysical measurements. The geophysical measurements are performed from a helicopter in order to obtain detailed information on the electrical and magnetic properties of the rock. If the proportion of exposed rock is limited, ground radar and seismic methods can be used to determine the thickness of the soil layer and the depth of the rock surface. It may then also be necessary to drill or dig down to the rock surface in order to obtain rock samples.

Geophysical measurements
Measurement of the physical properties of the rock

Surface water and groundwater conditions are mainly studied by means of hydrological mapping, inventory and sampling of watercourses, springs and wells. In the beginning of the investigations, a measurement programme is set up for all hydrological and meteorological parameters to be measured over a long period of time.

Seismic observation network
System for measuring earthquakes

During the initial phase, a seismic observation network is established to obtain data as a basis for assessing future seismic risks.

The results, mainly from the helicopter measurements and the geological mapping, are used to determine the location of the site within the candidate area and the positioning of the first boreholes to investigate the properties of the rock at depth. A drilling and investigation programme with 2–3 deep cored holes is carried out in order to determine whether the priority site can be accepted or whether it is clearly unsuitable for the deep repository. In connection with the drilling, seismic reflection surveys are conducted comprising kilometre-long, intersecting profiles. This method indicates the occurrence of major gently-dipping deformation zones, which can limit the utilization of the rock if they are at an unsuitable depth. The results of the seismic reflection measurements are also used for detailed planning of the continued drilling and investigation programme.

Seismic reflection
Method for investigating the rock with sound waves, similar to echo sounding

Rock type distribution, occurrence of major and minor fracture zones, chemical composition of the groundwater, hydraulic conductivity of the rock and the fracture zones, rock stresses and rock strength are investigated in the boreholes. Measuring equipment is then installed in the holes to study changes in groundwater pressure and chemical composition.

Obtained data are archived after quality control in a site-specific database. An overall evaluation is made of collected data, models are devised of rock conditions and ecosystems, and preliminary repository layouts are produced. The results of the initial site investigations are presented in preliminary reports with the same structure as the final reports, but on the basis of the limited body of data obtained in this phase.

The preliminary site description contains a compilation of the field studies that have been conducted within the candidate area. The compilation also describes regional conditions and presents collected data and interpreted parameters for the in-depth investigations that have been conducted on the priority site.

The preliminary facility description that is written based on the preliminary site description presents alternative proposals for a site plan and layout for the deep repository. There are, however, limited opportunities for adapting the facility to the actual conditions and properties of the bedrock at this stage.

As far as long-term safety is concerned, the body of material available after the initial site investigation is not expected to be sufficient to conduct a comprehensive safety assessment. The preliminary safety report will therefore mainly contain:

- A cross-check with the requirements and criteria that have been formulated in /13-10/.
- Comparisons with the conditions on the three sites that were analyzed in SR 97 /13-8/ and what can thereby be said about the expected outcome of a safety assessment based on data from a complete site investigation.
- Simple analytical nuclide transport calculations of the kind that were carried out in SR 97, with whatever new site-specific data are available.
- Presentation of data needs in the next stage of the site investigations, based on the results of the above-mentioned comparisons and calculations.

The investigations on the site are discontinued if the requirements on the rock discussed in Chapter 10 /13-10/ cannot be satisfied, for example if the rock at repository depth contains dissolved oxygen, excessive groundwater salinity, unsuitable rock-mechanical conditions, or extensive occurrence of workable minerals. The occurrence of major fracture zones is of great importance for how the investigated rock volume can be utilized for the repository.

The time required for the initial site investigation is estimated to be 1.5–2 years.

Complete site investigation

If the assessment shows that there are still good prospects of siting the deep repository on the investigated sites, complete site investigations follow, see Figure 13-5. The purpose of these investigations is to gather all the knowledge of the rock and its properties that is needed for a site description, a repository layout and a safety assessment.

The investigations during the complete site investigation phase are dominated by drilling and downhole investigations of various kinds. Continued mapping and measurements on the ground surface are also conducted during this phase, mainly to add detail to the geological mapping and to carry out detailed geophysical measurements. Supplementary investigations in the surrounding area are also conducted during this phase.

Percussion boreholes are normally drilled down to a maximum of 200 metres and cored boreholes usually to a depth of between 500 and 1000 metres. The boreholes are normally oriented between vertical (90°) and 50° from the horizontal plane. It may also be found necessary to drill short cored holes or holes deeper than 1,000 metres on the priority site or in its environs.

Percussion boreholes
Ordinary well boreholes in rock, usually 115 mm in diameter

Cored boreholes
Drilled to obtain a continuous sample of the rock in the form of drill cores. The borehole is usually 76 mm in diameter

The number of boreholes in the drilling programmes and the scope of the measurements cannot be specified in advance, since they are dependent on the conditions on the site. A reasonable estimate is that 10–20 cored holes and roughly an equal number of percussion holes are required.

Drilling is carried out in campaigns, where 3–4 holes are drilled simultaneously. This is followed by measurements and evaluation of the results. It takes several months to drill a deep hole, after which measurements are performed in the borehole for approximately six months. A preliminary estimate is that three drilling campaigns will be needed to obtain a good description of a site.

After each drilling campaign the rock models, the layout, and the evaluation of long-term safety are updated. The analysis of the uncertainties in the model descriptions is used to plan the next drilling campaign. The boreholes are positioned and aimed in order, for example, to verify the occurrence, location, orientation and properties of deformation zones and rock type boundaries. A number of holes are drilled to obtain data from potentially suitable repository volumes between the deformation zones. It is the properties and conditions in this bedrock that are most essential for the safety assessment. The results are evaluated in relation to the requirements and criteria discussed in Chapter 10 and with respect to remaining uncertainties in the description of the site. This evaluation serves as a basis for a decision as to whether the investigations should be continued with another drilling campaign or not. The investigations are discontinued when the reliability of the site description has reached such a level that the body of data for safety assessment and design is sufficient, or until the body of data shows that the rock does not satisfy the requirements.

The time required for the complete site investigations is estimated to be 3.5–4 years.

13.3.2 Environmental impact of the investigations

The general programme /13-7/ provides an overall description of the environmental impact to which the site investigations can give rise. The site-specific programmes that will be prepared during 2001 will contain more detailed information.

Measurements from a helicopter

During the initial site investigations, helicopter-borne geophysical surveys may be carried out, see Figure 13-6. These measurements will probably cover an area of 100–300 square kilometres and be conducted at an altitude of 30–60 metres along lines spaced at intervals of 50–100 metres. This will cause noise disturbances during a period of several weeks.

Measurements from the ground

Current conditions in the area's ecosystems, as well as how they are affected by the site investigations, will be documented. With this knowledge, it will also be possible to adapt the investigation activities so that valuable natural and cultural values can be protected and conserved and so that biological diversity is preserved. For the site where the deep repository will be built, this documentation provides baseline values for the continued follow-up of the evolution of the ecosystems in accordance with the monitoring programme that will be drawn up in conjunction with a siting permit application. As a part of the monitoring programme, measurements may be done in a reference area in order to obtain data on natural changes in an environment that is not affected by the investigations.

Figure 13-6. *Geophysical measurements from a helicopter. Instruments that record the magnetic and electrical properties of the bedrock are placed in measuring probes suspended underneath the helicopter. (Photo from measurements in Finland, photo-montage.)*

Measurements on the ground surface mainly involve geological mapping and ground geophysical surveys, but also to a lesser extent hydrological and hydro-chemical measurements and studies of soil and environmental conditions.

Geological mapping involves systematic observations and simple sampling of rock and soil to plot geological maps. Normal working tools are hammer and shovel. Geological bedrock mapping sometimes requires that the rock surface be temporarily exposed along profiles, often with the aid of a power excavator. The extent of the invasive work is dependent on the thickness of the soil cover. The soil cover is restored after mapping.

Various kinds of measuring instruments are used for geophysical surveys. Some are hand-held, while others require more complicated handling. For some methods, cables are laid temporarily (for a few weeks) along lines or in loops. They do not cause any damage to the ground or other environmental impact. In some cases, stakes are set out to mark measuring points or profiles. In seismic measurements, explosive charges are used which cause some noise and can create small pits or humps.

All in all, it can be said that geophysical measurements and geodetic surveys seldom cause permanent scars in the landscape. Dense vegetation must sometimes be cleared to provide visibility and accessibility along survey lines. Depending on the nature of the ground, this may leave some ruts, but in comparison with ordinary logging activities (felling, timber haulage, soil scarification and planting), this impact is insignificant.

Geodetic survey

Exact position measurement in a coordinate system

The hydrological and hydrogeochemical activities include mapping natural watercourses and taking water samples. Mapping of catchment areas and measurement of water discharge rates may, however, entail installing measuring stations in rivers and streams. A small measuring weir or other device can then be built to gather the water flow into a measurable stream. Measuring tubes may be positioned at suitable places for measurement of the level of the water table. Similarly, a small number of meteorological measuring stations may be deployed. None of this can normally be regarded as disturbing.

Drilling activities

Drilling is the heaviest activity conducted during the site investigations. It also causes the greatest environmental impact. Two main types of boreholes are drilled: cored boreholes and percussion boreholes. They entail different types of intervention on the site. The 10-20 deeper cored boreholes are drilled with bigger machines, see Figure 13-7. Since a large and long-lasting measurement programme will be executed in these holes, roads are needed up to the drilling site.

A work crew on a core drilling site normally consists of 3–4 persons, including a site geologist. Freight containers and sheds are placed near the drilling rig for use as storeroom, workshop, lab, site geologist's office and personnel quarters.

Flushing water is used to cool the drill bit and remove drill cuttings from the hole

Drilling a 1,000 metre deep cored borehole takes several months, which is followed by downhole measurements. During drilling, water is used to cool the drill bit. The water is fetched in a tank or pumped up from a well nearby. Most of the flushing water is recirculated, i.e. pumped up again from the borehole, after which it is conducted away for treatment in settling tanks and discharged into a suitable watercourse. If the salinity of the flushing water is too high, measures may be taken to prevent damage to the surrounding fauna and flora. Such measures may be dilution, discharge into larger watercourses, or hauling the water away in tanks.

The borehole is pumped out by means of compressed air. As long as pumping continues, the water level in the borehole will be depressed about 40–60 m below the normal groundwater level in the bedrock. The amount of this "draw-down" decreases with the distance from the borehole. At a distance of 200–400 m the drawdown is not noticeable. The groundwater level in the overlying soil layer is mainly dependent on the composition of the soil layer and the nature of the soil-rock interface. If the soil layer is dense, the drawdown in the soil is small. When pumping ceases, the groundwater level in the rock resumes its original level within a few days.

Percussion drilling is performed with ordinary well drilling rigs, which can be taken to the drilling site on crawler tracks. The groundwater level is depressed around the borehole during percussion drilling as well (which takes a few days). The size of the drawdown and the time for recovery are roughly the same as for core drilling.

Figure 13-7. *Example of worksite for core drilling.*

The boreholes will be distributed all over the entire investigation area. The location of each individual borehole is governed by scientific goals, but ordinary land use and the natural and cultural values of the site will be taken into consideration. The noise from a drilling rig is on a par with the noise from a timber harvesting machine, but the latter moves over larger areas than the percussion drilling rigs, which are stationary for most of the work.

Measurements in boreholes

After drilling, the boreholes are used for various kinds of measurements, usually during a period of about six months. After the measurements, permanent downhole equipment is often installed for long-term recording of e.g. groundwater levels. Measurements may need to be conducted for an extended period of time in some holes.

Hydraulic tests and water sampling requires lifting and measuring equipment. Hydraulic testing equipment is often mounted in freight containers or mobile carts that are positioned directly above the borehole. In connection with water injection tests and pumping tests, water is handled in a way that resembles flushing and return water handling in connection with drilling. But the water quantities are much smaller, with the exception of long-term pumping tests. If the water has high salinity, it must be disposed of in the same manner as that recovered from drilling.

Water injection test and pumping test

Methods for measuring the hydraulic conductivity of the bedrock

Construction of logging roads

Personnel and equipment for drilling and measurement can be transported on roads similar in standard to ordinary logging roads. Without roads, personnel and equipment have to be transported off-road, causing rutting of the terrain, which can be extensive and more environmentally harmful than roads. The existing road network in the investigation area will be used wherever possible, but it may be necessary to construct new logging roads, in which case adjustments will be made so the environmental damage is acceptable. In principle, a service road to the nearest existing road and a turnaround at the borehole are required for each borehole. The new logging roads can also be of use to the landowner and for outdoor recreational activities, particularly after the site investigation is over.

Transportation

Both materials and personnel will be transported on the roads throughout the site investigation phase. Most of the transportation will consist of the personnel's car trips. Heavier transport will mainly take place in connection with drilling and during the initial measurement period.

13.4 Encapsulation plant and canister factory

The site investigation phase also includes gathering data for siting of the encapsulation plant and the canister factory. Regarding the siting of the encapsulation plant, SKB's main alternative is a siting at CLAB. A siting at the deep repository is being studied as a possible alternative. Both alternatives have previously been studied /13-11, 12/, and a comparative study is currently under way.

The work leading up to the submission of an application for a permit to establish the encapsulation plant on a specific site consists for the most part of conducting supplementary studies. Furthermore, the supporting documentation for the permit application – i.e. the preliminary safety report and the EIS – is updated. The experience obtained from the Canister Laboratory is important for the work /13-13/.

The encapsulation plant takes six years to build

Construction of the plant can begin as soon as a permit has been obtained, and the construction time is estimated at six years.

Fabrication of canisters, i.e. fabrication of inserts and copper shell plus assembly, is planned to be carried out in a canister factory. In SKB's judgement, it needs to be in operation for a year or so before the encapsulation plant can be put into operation. The canister factory is a conventional type of factory. Questions that must be considered in connection with siting concern e.g. transport to and from the factory plus societal aspects, such as labour supply and industrial environment. Alternatives that will be studied are a siting in the same region as the encapsulation plant or the deep repository, but completely different alternatives may also be considered.

13.5 Siting studies

Final disposal of spent nuclear fuel requires a system of facilities described in Chapter 6. Studies of the entire system and the relationships between different facilities are needed for each siting alternative. Detailed plans need to be drawn up for handling of materials and transport to the deep repository. Geographically, these studies will impinge upon several parts of a municipality or a region. Examples of questions that must be clarified are:

- Which harbours are to be utilized for different types of goods.
- Which road and/or rail routes can be used or need to be built out.
- Where and how canister fabrication, preparation of bentonite etc. can be arranged.

In addition to technical and economic aspects, the studies will also deal in depth with environmental consequences and societal effects. Supplies of labour and resources, as well as local and regional development opportunities, must be studied. Here, relevant municipalities and regions must play a major role when it comes to ideas and initiatives.

13.6 Research, development and demonstration

In parallel with the site-specific work with investigations, design, safety assessments and siting studies, the programme for research, technical development and demonstration continues. Ongoing activities are described exhaustively in RD&D-Programme 98, and an updated account of the current state of knowledge and plans will be provided in RD&D-Programme 2001, which will be submitted to the Government in September 2001. The knowledge base will continue to be augmented and the safety assessment methodology will be further refined, based among other things on the review that has been done of SR 97 (see Chapter 7). The work at the Äspö HRL and the Canister Laboratory with development and full-scale testing of deposition methods and encapsulation technology will continue. During the coming years, variants of the KBS-3 method will be studied, such as for example emplacement in Medium Long Holes and the use of copper canisters with a different wall thickness (see section 6.4).

In addition to the site-specific documentation, a siting application for the deep repository must be accompanied by a documentation of the entire deep repository system and the continued work on the selected site. This documentation is planned to include the following reports:

- An updated system analysis with a description of the entire system for final disposal of the spent nuclear fuel and a comparison of the variants in the design of the KBS-3 system that are still of interest to pursue further. In this report, the results of the technology development that has taken place during the site investigation phase are described, the technology choices that have been made are justified, a comparison is made of how different choices affect long- and short-term safety, and the way different parts of the system influence each other is described. The system analysis should also show that safety can be guaranteed in all steps and parts of the system.
- A plan for the detailed investigation phase with a description of how the construction of the tunnel and/or shaft down to repository depth will be accomplished and how the rock will be investigated in greater detail from tunnels at repository depth. The construction of buildings, roads and possibly railways above ground will also be described. The environmental impact of the construction work and the measures that will be taken to limit this impact will be described together with a monitoring programme. A plan will also be presented for how consultations with concerned municipalities will be held during the detailed characterization phase.
- An account of the zero alternative, where supervised storage of the spent fuel in CLAB continues indefinitely (perhaps for several hundred years). Such an account is given in Chapter 4 of this report and will also be included in future environmental impact statements.

14 Programmes for Northern Uppland, Oskarshamn and Nyköping

Programmes for site investigations at Forsmark and Tierp in Northern Uppland and at Simpevarp in Oskarshamn will be prepared during the first half of 2001. In the case of Nyköping, test drilling is not included, but other studies are. The site-specific programmes are based on the general programme described in the preceding chapter and adapted to the state of knowledge and specific questions which have been identified for each site. The programmes also need to be adapted so that viewpoints from the municipality, landowners and nearby residents are taken into account, as well as natural values and other interests. This chapter sketches the scope of the initial phase of the programmes, including other studies that need to be done for the siting alternatives. The programmes are preliminary, and the intention is that further detail will be added during 2001 after discussions with concerned municipalities, regulatory authorities, landowners, nearby residents and other particularly affected individuals.

14.1 Programme overview

Preliminary programmes for the initial phase of the site investigations in Northern Uppland, Oskarshamn and Nyköping are presented in the following. The main features of the activities during the site investigation phase are described in the preceding chapter, so the description here is focused on that which is specific for each siting alternative.

In early 2001, SKB plans to send an inquiry concerning continued participation to the municipalities included in the proposed programme, i.e. Tierp/Älvkarleby and Östhammar in Northern Uppland, Oskarshamn and Nyköping. Assuming that the regulatory authorities and the Government render a favourable judgement on the material now being presented, it is SKB's judgement that the municipalities should be able to make a decision on site investigations by the end of 2001.

The site-specific programmes presented here are preliminary and will be further elaborated during the first half of 2001. They will be finished in good time to serve as a basis for the municipalities' decisions on site investigations. SKB intends to initiate discussions of the programmes with concerned municipalities, landowners, nearby residents and other particularly affected individuals in early 2001.

The programmes focus on the first year of the site investigation phase, since investigation results, site evaluations and other studies done during this period need to be taken into account in the detailed planning of the remaining site investigations. The programme for the latter part of the site investigation phase cannot be specified in greater detail today than has been done in Chapter 13.

When the site investigations are started, concrete planning of the environmental impact statement and the safety assessment that will comprise vital supporting documents for a siting application will also begin. What is important in the initial phase is to identify and delimit the questions that need to be addressed on the site in question as soon as possible. This can influence what investigations need to be done and what other data need to be collected.

14.2 Northern Uppland

The aim of the programme for Northern Uppland is to collect data as a basis for a complete deep disposal system in the region. Two siting alternatives for the deep repository are being further studied: Forsmark and Tierp north/Skutskär. In addition, the prospects of siting other facilities in the deep disposal system in the region are being studied.

The municipalities that are directly affected by test drilling are Östhammar and Tierp. Älvkarleby municipality is also affected, since a solution where the deep repository is sited in Tierp involves transport via the harbour in Skutskär as the main alternative. SKB therefore considers the participation of the municipalities of both Tierp and Älvkarleby to be a prerequisite for further study of this alternative.

During 2001, SKB will discuss plans for a possible continuation of the siting work in the region and in the different municipalities with all three of the affected municipalities in Northern Uppland. The statements of opinion issued by the municipalities and the reviewing bodies on the feasibility study comprise an important basis for these discussions and will be taken into account in the continued work. Another basis for the discussions is the programme sketched below.

14.2.1 Management and organization

The planned site investigations and other activities in Northern Uppland entail for SKB's part a more far-reaching and long-term establishment in the region than has been the case so far. The work will be conducted in project form, with the project organization stationed in the region. One organization will presumably be in charge of both site investigations. The local information offices established for the feasibility studies in Östhammar, Tierp and Älvkarleby will remain in place until further notice.

Fully established, the project will have a workforce of approximately 40 persons. In addition to employees for project management, consultation, information etc., the workforce includes consultants and contractors for e.g. roadwork, snow clearance, exploratory drilling, geological measurements, studies and general services.

14.2.2 Consultation

The site investigations do not require a permit. SKB notifies them to the county administrative board and the municipality in accordance with Chapter 12 of the Environmental Code

The deep repository does require a permit. SKB notifies it to the county administrative board in accordance with Chapter 6 of the Environmental code. This leads to extended consultation.

The site investigations do not require a permit, but will be notified to the county administrative board and the municipalities in accordance with Chapter 12 of the Environmental Code. SKB will hold discussions with the county administrative board, the municipality, landowners, nearby residents and other particularly affected individuals in order to limit the disturbances caused by the investigation activities.

Planning for consultation in accordance with the Environmental Code is described in Chapter 13. The consultation should build further on the established forms, with meetings chaired by the county administrative board in Uppsala County. Before SKB makes a notification of early consultation as set forth in Chapter 6 of the Environmental Code, the individuals expected to be particularly affected should be identified. At the start of the consultation, SKB will inform and summon affected individuals and authorities to the consultation meetings.

Since the Environmental Code requires consultation to be tied to a specific site, there will have to be two notifications and two separate consultations, one for siting in Östhammar and one for Tierp. In view of the importance of the deep repository establishment for the region as a whole, coordination between the two consultation procedures would be desirable. SKB intends to discuss how such coordination can best take place with the county administrative board and the concerned municipalities.

The possibility of siting the encapsulation plant in Northern Uppland will also be discussed within the framework of these consultations.

14.2.3 Siting studies

Linked to the two siting alternatives for the deep repository, SKB intends to study an establishment of the encapsulation plant in Northern Uppland. The canister factory is not linked to the nuclear installations, but there may be advantages to siting canister fabrication in the region as well.

The deep repository, possibly with the addition of the above-mentioned plants, is a large and long-term industrial project which brings up a number of other questions concerning the region as a base for SKB's operation. These questions concern infrastructure, transport and communications, suppliers, recruitment of qualified personnel, etc. These questions must be viewed in the light of the fact that the centre of gravity of SKB's entire operation, including central management and staff functions, will eventually be in the region where the deep repository is located.

14.2.4 Investigations and studies

Forsmark

The area in Forsmark being considered for site investigations is approximately 10 square kilometres in size and extends from the Forsmark industrial area southeast to Kallrigafjärden bay, see Figure 14-1. Figure 14-2 shows a photomontage that gives some idea of the type of terrain and location. It also shows the projected position of the deep repository's surface facility adjacent to the existing SFR facilities. A transport tunnel can be built from the surface facility to a repository somewhere within the priority area. The projected system design is described in Chapter 11, Figure 11-5.

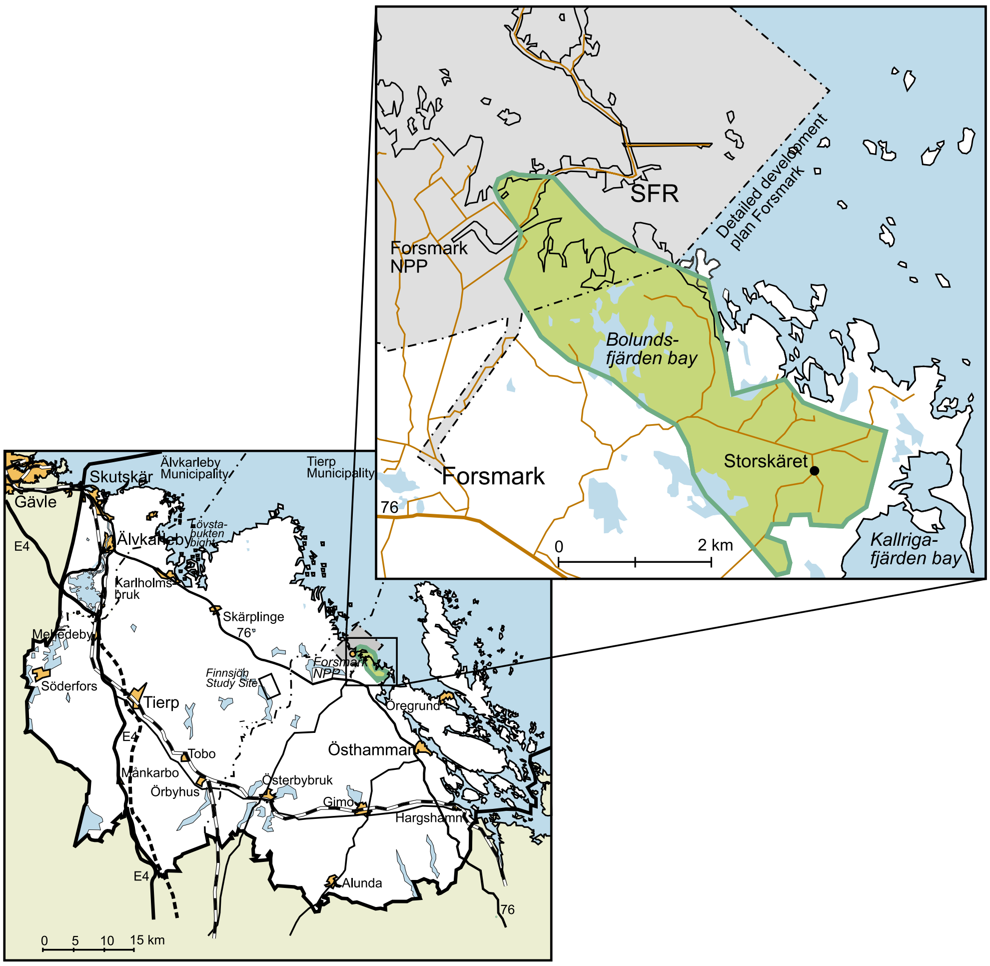


Figure 14-1. *Area in Forsmark that is of interest for site investigations.*

***Figure 14-2.** Photomontage of proposed positioning of the above-ground portion of the deep repository at SFR. The area of interest for site investigations is shown in the background.* *Photo Göran Hansson/N*

Investigation of the bedrock

The initial part of a site investigation in Forsmark is planned with the guidance of the general goals described in Chapter 13, but adapted to local conditions. The prioritized area is relatively small and geologically well-delimited to a so-called tectonic lens, surrounded by substantial deformation zones. With the systematics illustrated in Figure 13-5, it can be said that we are starting in a situation here where a site has actually already been identified. It should therefore be possible to start drilling relatively soon after a decision has been made on site investigations.

Relatively detailed geological maps and other geoscientific material on the area are available from the feasibility study. Extensive data on bedrock conditions exist from previous investigations at Forsmark and from the construction of SFR. Taken together, this material provides a good idea of how the investigations in the initial phase should be planned to obtain answers to the geoscientific questions that are specific for Forsmark. In addition to the site-specific questions that have been identified in section 12.3, there are other, general questions that must always be answered. These include the occurrence and frequency of dykes and fracture zones, the hydraulic conductivity of the fracture zones and the surrounding bedrock, flow paths for the groundwater, and hydrochemical and rock-mechanical conditions.

Owing to the location of the area in a limited tectonic lens surrounded by large fracture zones, the three-dimensional shape of the lens must be studied to answer the question of whether the repository will fit in the site and, if so, how it should be configured.

Geophysical measurements from a helicopter will be conducted at an early stage which, together with detailed geological mapping and geophysical measurements from the ground surface, will provide information on the structure of the lens and where steeply-dipping fracture zones may be present. Seismic reflection surveys will be conducted to map any gently-dipping deformation zones. Percussion boreholes (down to about 200 metres) will be drilled to supplement surface data and verify interpretations of e.g. fracture zones. Data from airborne geophysical surveys and general mapping of the bedrock will be used to place the tectonic lens in its regional context.

A first campaign of deep cored holes, preliminarily 3–5, will be drilled in a pattern so that they provide, in combination with the surface investigations, knowledge of the three-dimensional shape and internal structure of the lens. This exploratory drilling can be carried out in parallel with other studies. It should be possible to answer other questions by means of the measurements made in the boreholes (see Chapter 13).

An important part of the programme is long-term recording of biological, hydrological and chemical conditions to enable natural variations to be followed and the impact on them of a deep repository to be assessed.

The geological-structural picture that is obtained from these investigations should be able to clarify whether there are good prospects for a repository in the area. Cross-checks will be made continuously with the safety assessment's need for data, and a preliminary safety assessment will be made at the end of the initial investigations, see Chapter 13. If this has a positive outcome, the investigations will continue with a complete site investigation. The purpose will then be to obtain the data on minor fracture zones and other factors that are needed for a detailed repository layout and a safety assessment.

If the initial site investigation in Forsmark does not have the expected results, the possibility of conducting testing drilling in other siting alternatives – above all Hargshamn – will be discussed.

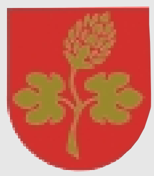
Before any drilling is started, further detail will be added to the inventory of fauna and flora already conducted with a special focus on conditions at possible drilling sites. Evaluations will also be made of the environmental impact of the site investigations. The owner of most of the land, Sveaskog, must give its permission for the investigations.

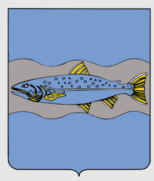
Design, land and environment questions

In parallel with the investigations of the bedrock, other studies in the general site investigation programme will also be commenced. This includes design, aimed at arriving at a site-adapted layout of facilities and technical supply systems above and below ground, and plans for the construction and operating phases. Examples of important tasks for the design process during the initial site investigation are to explore the conditions for rock construction, mainly on the basis of data obtained from boreholes, and to evaluate alternatives for transport and handling of rock spoils and backfill material. The environmental impact statement will make use of data from the investigations and from the design work. Alternative solutions will be evaluated and judged based on their impact on the environment.

Tierp/Skutskär

Due to the size of the area in question, the site investigations first have to be concentrated on identifying, with the aid of surface investigations, a site that can be geoscientifically prioritized for drilling, and which is at the same time suitably situated in relation to infrastructure and environmental factors. Once the site has been determined, the next step is to carry out an initial test drilling campaign in order to determine the properties of the granite in respects important for the deep repository.





A site for drilling must first be defined within the designated area

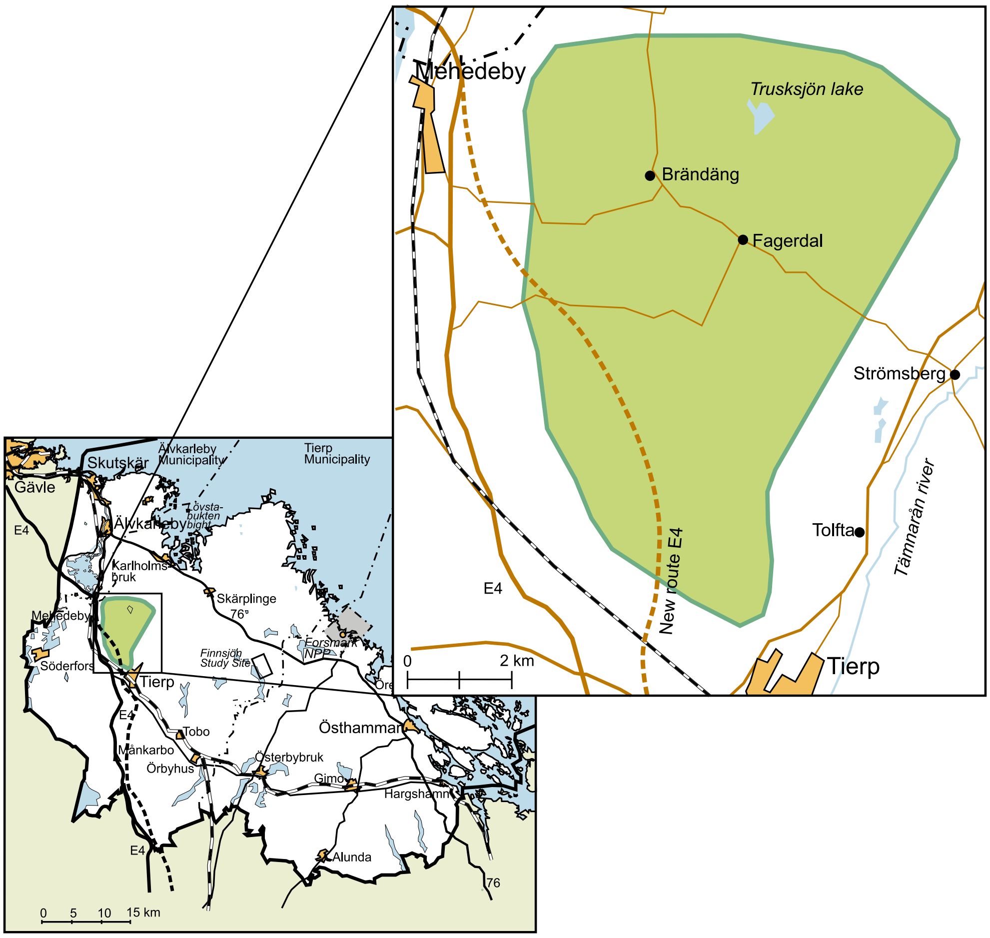


Figure 14-3. *Area in Tierp that is of interest for site investigations.*

The area in question in Tierp Municipality (see Figure 14-3) offers different prospects for starting a site investigation than Forsmark. The area in Tierp is large, about 60 square kilometres, and covers a part of the even larger granite massif (the Hedesunda granite). The proportion of exposed rock is low and the knowledge available on the bedrock in the area is limited. Figure 14-4 is based on a satellite image and gives an overview of the location of the area in relation to towns and infrastructure. Among other things, it shows the harbour in Skutskär and the route of the East Coast Railway. The proposed system design for this alternative is presented in Chapter 11, Figure 11-7.

The availability of a large area with suitable (as far as can be judged) bedrock provides flexibility and thereby improves the prospects of finding a suitable rock volume.

Investigations of the bedrock

The site investigations have to start "from the bottom", with an initial phase of preparatory studies – geoscientific and others – aimed at mapping the bedrock and defining a site where drilling can begin (cf. Figure 13-5). Once the site has been determined, the next step is to carry out an initial test drilling campaign in order to check that the mapping is correct and clarify the properties of the Hedesunda granite in respects important for the deep repository.

The main task in the initial phase is to map rock types and fracture zones and then identify a site for the deep cored boreholes. Since the mapping process will require interpretations of different types of geophysical measurements, these

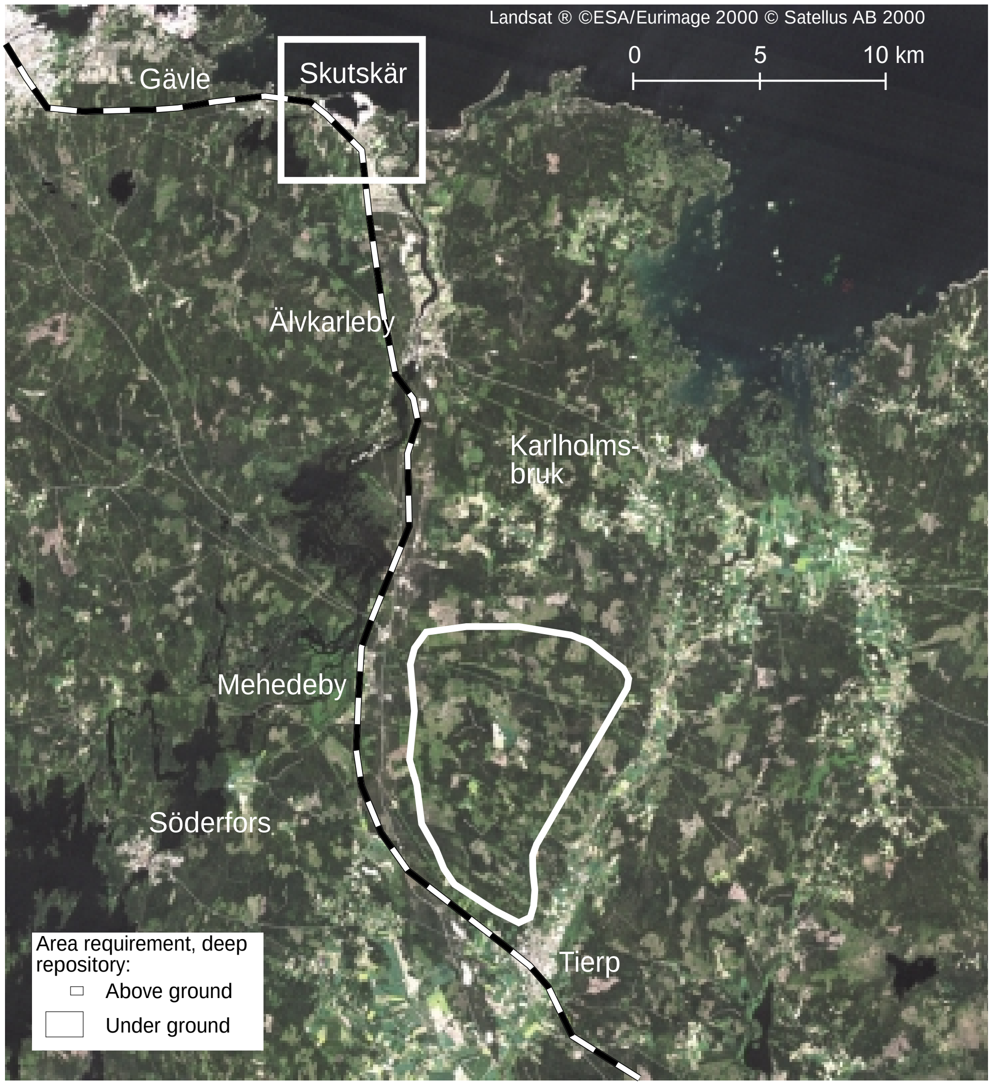


Figure 14-4. *Satellite image of the area of interest for site investigations and the harbour in Skutskär.*

interpretations need to be verified in order to judge the reliability of the mapping. Verification can be done by exposing the bedrock by means of trenched profiles or short boreholes. As far as the properties of the granite massif are concerned, the body of knowledge is too limited to enable site-specific questions to be identified. Based on general geological grounds and experience from investigations in other large granite massifs, the following questions should be answered:

- Depth (should be at least 1 kilometre) and homogeneity of the granite body.
- Occurrence and hydraulic conductivity of fine-grained granite dykes.
- Distance between steeply- and gently-dipping fracture zones.
- Hydraulic conductivity of the bedrock (in rock mass and fracture zones).
- Occurrence and importance of high rock stresses.
- Potential for radon occurrence.

The mapping should provide information on the internal structure of the granite and how its composition varies. It is important to identify steeply-dipping and possibly also flatly-dipping fracture zones. Measurements will be performed from a helicopter and on the ground and cover both the area and its environs. A few deep cored boreholes should provide answers to the above-mentioned questions and provide a basis for a preliminary safety assessment. If the preliminary safety assessment after the initial site investigation shows that the Hedesunda granite has favourable properties, it should be possible to proceed to a complete site investigation on the selected site. If the site is unsuitable due to some local condition at repository depth, while the other properties of the bedrock are favourable, one possibility may be to undertake investigations on another site in the area.

The investigations of land and environment factors that are included in an initial site investigation according to Chapter 13 are applicable to the priority area in Tierp. Relatively extensive inventories of flora and fauna, protection interests, etc. are needed as a basis for defining an exact site within the area and evaluating the environmental impact of a site investigation. Another important task is to clarify the standpoint of different landowners on test drilling and a possible deep repository establishment.

Design, land and environment questions

The design work will initially mainly be concerned with facilities and infrastructure on the site of the deep repository's surface facilities. These may be located on the site or at a suitable tunnel distance from it. There is great flexibility in adapting the positioning and layout of facilities, traffic connections etc. to local conditions. Furthermore, facilities in the harbour at Skutskär need to be designed and the transport options between harbour and deep repository studied. Since neither the site nor the system design are given, the work must be broadly conceived to start with, whereby different alternatives are sketched and evaluated. Transport solutions will be devised at an early stage so that they can be explained to and discussed with concerned parties. The same applies to the prospects of locating parts of the activities at Skutskär. The impact on the environment will be studied and evaluated for the different alternatives as a basis for the environmental impact assessment.

14.3 Oskarshamn

The aim of the programme for Oskarshamn is to collect data as a basis for a complete deep disposal system in the municipality. This entails that the encapsulation plant is located on the Simpevarp Peninsula, in direction connection with CLAB, as the main alternative. The main alternative for the deep repository is that the surface facilities are located on the Simpevarp Peninsula and the repository as close by as rock conditions permit. Initial site investigations will be conducted in the Simpevarp area for the purpose of defining such a site. Complete site investigations will then be carried out on this site. Other alternatives for the deep repository may be considered if the investigations in the Simpevarp area do not have the expected results.

During 2001, SKB will discuss plans with the municipality of Oskarshamn for a possible continuation of the siting work in the municipality. The municipality has presented preliminary plans for the preparation of a decision on site investigation.

14.3.1 Management and organization

The site investigation process in Oskarshamn will be conducted in the form of an autonomous project with a locally stationed organization. SKB already has a large operation in Oskarshamn, and a study will be made of how the site investigations are to be coordinated with existing activities. The resources for the site investigations will be closely tied to the Äspö HRL.

Fully established, the project will have a workforce of approximately 30 persons. In addition to employees for project management, consultation, information etc., the workforce includes consultants and contractors for e.g. roadwork, snow clearance, exploratory drilling, geological measurements and studies.

14.3.2 Consultation

The site investigations in the Simpevarp area will be notified to the county administrative board and the municipality, in accordance with Chapter 12 of the Environmental Code. SKB will hold discussions with the county administrative board, the municipality, landowners, nearby residents and other particularly affected individuals in order to limit the disturbances caused by the investigation activities.

Planning for consultation is described in Chapter 13. A forum for EIA consultations on nuclear waste issues (EIA forum in Kalmar County), chaired by the county administrative board, has existed for a long time. The EIA forum started when the question of establishing the encapsulation plant at CLAB began to be discussed and has since served, among other things, as a body for competence buildup and discussion during the feasibility study in Oskarshamn. SKB proposes that the consultation procedure in Kalmar County build further on the foundation that has been laid. When the necessary data have been collected, SKB intends to make a notification of early consultation to the county administrative board, as set forth in Chapter 6 of the Environmental Code. The individuals expected to be particularly affected should be identified at this time. When consultation pursuant to Chapter 6 of the Code is begun, SKB will inform and summon affected individuals and authorities to the consultation meetings. SKB wants to discuss the forms for the consultation with all those involved at an early stage to ensure that they will be expedient and satisfy the requirements of the Environment Code.

14.3.3 Siting studies

With the encapsulation plant located at Simpevarp, there may be advantages to having canister fabrication in the municipality or the region as well. The prospects for this will be studied. The applied parts of SKB's development activities are located today at the Äspö HRL and the Canister Laboratory, both in the municipality of Oskarshamn. An establishment of the deep repository and possibly the canister factory would entail that nearly all of the operating activities were collected in the municipality. It is then only natural that the rest of the company's research and development, as well as management and central staff functions, should be placed there. These questions will be further studied as a part of the activities during the site investigation phase.

14.3.4 Investigations and studies

Simpevarp

A site investigation at Simpevarp should in the initial phase cover both the Simpevarp Peninsula and large areas to the west of it. The area is relatively flat and the bedrock has a relatively high proportion of outcrops. The granite areas to the west that are of interest cannot be delimited on geological grounds. Figure 14-5 shows a preliminary delimitation based on the extent of the area covered by the feasibility study's field checks. The availability of large areas with good geological prospects also entails good chances that a site investigation will lead to the desired result. Preliminarily, the part of the area located closest to the Simpevarp Peninsula is prioritized, since nearness to a surface facility on the peninsula would provide logistic and environmental advantages. In the initial phase, however, investigations will be conducted over a considerably larger area within the granite terrain of interest.

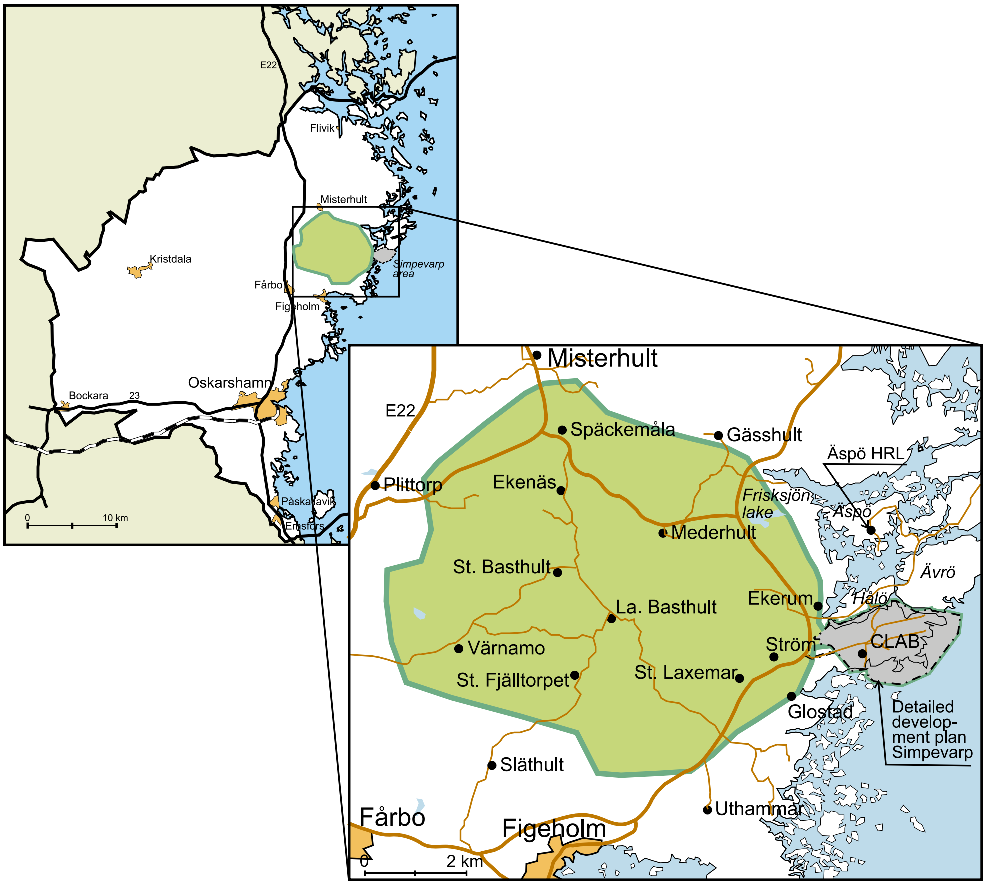


Figure 14-5. *Area in Simpevarp that is of interest for site investigations.*

SKB also intends to investigate the Simpevarp Peninsula itself, even though it is not prioritized from a geological viewpoint. A siting on the Simpevarp Peninsula would entail many advantages from an establishment viewpoint, and SKB therefore deems it worthwhile that the peninsula's bedrock also be investigated in depth. An investigation of the peninsula is also warranted by the fact that the access tunnel to a deep repository west of Simpevarp would probably start on the peninsula.

Figure 14-6 is a photomontage showing the Simpevarp Peninsula with the NPP, CLAB and where the deep repository's industrial facility can be located. As a first-choice alternative, a transport tunnel will be built from the surface facility to the repository, with a projected location in the area towards the west visible in the background, or possibly beneath the Simpevarp Peninsula. Possible alternatives for the system design are presented in Chapter 11, Figure 11-16.

Investigations of the bedrock

In the initial phase the site investigation will be focused on investigating the conditions at depth on the Simpevarp Peninsula and on identifying a site further west that is suitable for test drilling. On the Simpevarp Peninsula, it should be possible to start drilling soon after a decision is made for site investigation. The conditions west of the peninsula are relatively well known, and the site-specific questions are discussed in section 12.3. Owing to the size of the area, extensive investigations are required from the surface before subareas can be identified (see Figure 13-5) for test drilling.

The main question for the Simpevarp Peninsula is whether the area is big enough for a deep repository, given the existing fracture zones. Moreover, information is lacking on those properties of the bedrock at depth within the peninsula that are generally of great importance for long-term safety and constructability. A few deep boreholes, together with data from surface investigations and existing rock caverns

Figure 14-6. *Photomontage of proposed positioning of the above-ground portion of the deep repository at Simpevarp. The area of interest for site investigations, besides the Simpevarp Peninsula itself, is shown in the background.*

and tunnels, should suffice to determine whether it is worthwhile to proceed with complete site investigations on the peninsula. The existing facilities limit the opportunities for carrying out some of the geophysical ground and airborne measurements that are included in the general programme, mainly with electrical methods.

For the area west of the Simpevarp Peninsula, the main question for the investigations is to find out the location and properties of fracture zones and thereby where bedrock blocks are located within which a deep repository can be built. As far as the properties of the bedrock are concerned, data from the Äspö HRL and the boreholes at Laxemar provide guidance on what conditions can be expected at depth.

The investigation programme for the area west of Simpevarp will mainly follow the programme presented in section 13.3. Geophysical measurements from a helicopter will be performed over a large area. The extent (larger than in Figure 14-6) is based primarily on the need to include natural hydrogeological boundaries within the area. Supplementary geological mapping and geophysical investigations will be done on the ground and include studying the occurrence of dykes of fine-grained granite. Trenches will be dug and short percussion boreholes drilled to augment surface data and verify interpretations.

On the basis of these investigations and other factors, one or two minor areas will be delimited in which seismic reflection measurements will be performed. Test drilling will be commenced when a priority site has been selected. Long-term recording of biological, hydrological and chemical parameters will be started. How the investigations are organized will depend to a great extent on local conditions, especially the occurrence of fracture zones. A few deep boreholes should however be able to provide data for a preliminary safety assessment. If this has a positive outcome, the work will continue with a complete site investigation, provided the investigations on the peninsula do not warrant a continuation there. In the event of a negative outcome, the possibility of conducting investigations on another site in the area or in an other part of the municipality may be discussed.

In parallel with the geoscientific investigations west of Simpevarp, inventories will be made of flora, fauna and special protection interests, etc. in the same area. Another important task before starting the investigations is to clarify the standpoint of different landowners on test drilling and a possible deep repository establishment.

Design, land and environment questions

To start with, the design work will concentrate on the layout of the deep repository's facilities and activities above ground. For this purpose, good, precise information is available on several alternative sites on the Simpevarp Peninsula, plus a natural location for the encapsulation plant. Preliminary draft layouts of the repository's underground parts will also be prepared at an early stage for the two possible sitings: the Simpevarp Peninsula and an area west of there. This will be done to obtain a preliminary idea of whether the repository will fit inside identified rock blocks and how access tunnels should be located for the different alternatives.

Transport of backfill material and rock spoils is also a question that should be studied at an early stage.

Together with the results of the geoscientific investigations and system-related studies, these studies will form the basis for selecting a site for the repository. When this has been done, the design work can proceed to preparing detailed facility descriptions that include all parts of the deep disposal system. Data from the investigations and from the design work will be used in preparing the environmental impact statement. Alternative solutions will be evaluated and judged based on their impact on the environment.

14.4 Nyköping

Nyköping is included in the site investigation phase for the sake of comparison, since Fjällveden's geological setting differs from that in other siting alternatives, and furthermore as an alternative if other sitings cannot be realized. The proposal of a siting of the deep repository at Skavsta/Fjällveden was put forth after the circulation of the preliminary feasibility study report for comment and has not been reviewed like other siting alternatives. SKB intends to continue to study the feasibility of the proposed siting and try to clarify whether the support of the community can be obtained. The programme also includes conducting a safety assessment with modern methods based on data from previous investigations in Fjällveden. New test drilling is not being considered.

14.4.1 Consultation

SKB plans to continue consultations with the municipality and the county administrative board under established forms.

14.4.2 Studies - establishment prospects

The technical prospects for an establishment in Skavsta/Fjällveden have been presented in sections 11.4.5 and 12.4. Important questions that must be studied more closely are how transportation from Oxelösund harbour to Skavsta can be arranged and what the prospect are for e.g. construction of a new road or rail line. Other important questions are the rock engineering conditions for building a long connecting tunnel between Skavsta and Fjällveden and the design of the operating area that should be established within or south of the Fjällveden area. Environmental consequences and land use aspects of alternative system solutions will be cursorily examined. Figure 14-7 contains a map with the localities where facilities could be built if the deep repository were to be sited in accordance with the Skavsta/Fjällveden alternative.

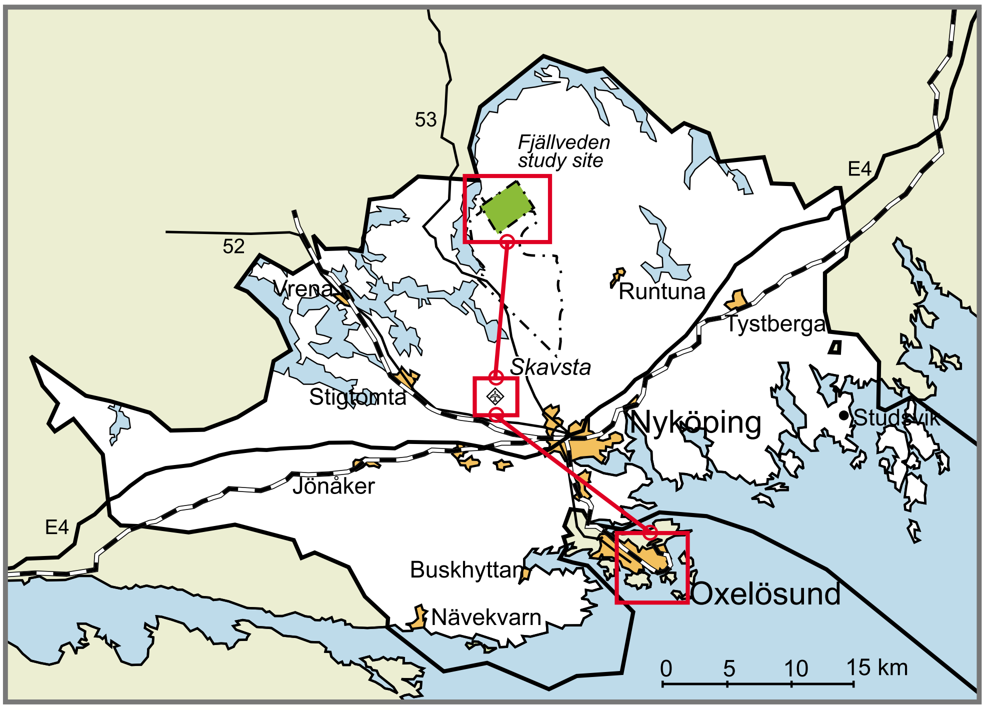


Figure 14-7. *Map with the localities where facilities could be built if the deep repository were to be sited in accordance with the Skavsta/Fjällveden alternative.*

14.4.3 New safety assessment

SKB considers it urgent that the geological setting represented by Fjällveden also be included in the next phase. There is no need to carry out test drilling, since data from repository depth are available from the study site investigations that were performed in the early 1980s. In order to get a better idea of the geological prospects for a repository in Fjällveden, SKB will conduct a safety assessment with the modern methodology used in SR 97.

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Account of completed consultations

In its decision of 24 January 2000 on SKB's RD&D-Programme 98, the Government states that SKB shall consult with "concerned municipalities, county administrative boards and regulatory authorities" in connection with the preparation of the accounts which the Government has stipulated as conditions for the continued research and development work.

This Appendix gives an account of how consultations have been conducted during the work with the integrated accounting. Consultation is first put in the larger context of, on the one hand, the regular public review and circulation for comment of SKB's programmes that has been carried out of every account since 1986, and on the other hand the dialogue and collaboration with municipalities, county administrative boards, regulatory authorities and many other affected parties that has been continuously carried out as a part of SKB's siting studies, in particular in conjunction with the feasibility studies.

SKB believes that the circulation for comment, review, consultation and information that has been carried out provides a good point of departure for the consultation procedure pursuant to the provisions of the Environmental Code that SKB plans to initiate in conjunction with the transition to the site investigation phase.

1. Background

History - the Swedish nuclear power programme and the management of nuclear waste

An account of the political decisions that have been taken concerning the thrust of the Swedish nuclear power programme and nuclear waste management has been given in a special report /1/. Crucial decisions are noted, such as the type and number of reactors, reprocessing or direct disposal of spent nuclear fuel, the operating life of the NPPs, etc. Furthermore, an account is given of the decisions surrounding what has gradually emerged as SKB's main alternative, the KBS-3 method.

Circulation for comment and review in conjunction with the RD&D programmes

Every third year since 1986, SKB has submitted R&D and RD&D programmes to SKI pursuant to the requirements of the Nuclear Activities Act. The programmes are circulated for comment to public authorities such as county administrative boards, the Swedish EPA, the National Board of Housing, Building and Planning and SSI (the Swedish Radiation Protection Institute), as well as feasibility study municipalities, local safety committees and institutes of higher learning. Environmental organizations as well as central and local opinion groups are also given an opportunity to have their say. For example, RD&D-Programme 98 was sent to sixty-three reviewing bodies for comments. Forty-five responses were received.

Based on the circulation responses and its own review, SKI has compiled a body of material to serve as a basis for the Government's decisions. These decisions have guided the thrust of SKB's work. A historical summary of the most important aspects and viewpoints was provided in RD&D-Programme 98.

Discussion and consultation on method selection and technology

Twice a year in recent years, SKB has held meetings with SKI and SSI on method selection and technology. Method selection and technology is also included in the annual theme day on SKB's activities in which SKI, SSI, KASAM and the Ministry of the Environment participate.

Information and consultation during the siting work

Information and consultation work is pursued in conjunction with the ongoing feasibility studies. The work is particularly pursued locally and regionally. One element of this consultation has been the broad circulation for comment of the preliminary reports. Accounts are given in the feasibility studies' final reports for information and consultation, as well as for how viewpoints from the circulation and commentary procedure have been dealt with.

SKB's public information activities revolve around the information offices in each feasibility study municipality. There the public has an opportunity to ask questions, obtain material and voice their views. SKB also conducts outreach activities aimed at associations and schools and visits the towns in the municipalities with mobile exhibitions. Furthermore, SKB participates regularly in local trade fairs and similar arrangements. M/S Sigyn visits the feasibility study municipalities with exhibitions during the summer. Another important part of these activities is study visits to SKB's facilities.

The feasibility study municipalities have been given an opportunity by the Government to obtain up to SEK two million per year from the Nuclear Waste Fund for local competence buildup and information activities. The municipalities have used these funds in different ways. All municipalities have formed reference groups in which all parties in the council have been offered a chance to participate. Investments have been made in competence development for these groups. Public seminars, debates and meetings have been held.

In May 1996, a "National Coordinator for Nuclear Waste" was appointed by the Government. The purpose was to coordinate the information and research activities deemed necessary by the municipalities. A meeting forum was formed in November 1997: the National EIA Forum for Nuclear Waste. The principal purpose was to create consensus on what questions should be dealt with in the EIA work and to provide an opportunity to deal with questions of general importance for the contents of an environmental impact statement. Meetings were arranged 2–3 times a year. The work has been described in annual reports on the National Coordinator's activities, which have been submitted to the Government.

After June 1999, the title "National coordinator for Nuclear Waste" was changed to "Special Advisor on Nuclear Waste" and was tied more closely to the Government Offices than before. The Special Advisor is supposed to follow the ongoing work of finding a site for the deep repository and assist the Government Offices with advice in dealing with matters pertaining to the nuclear waste field. The Special Advisor is also supposed to coordinate educational and information activities between concerned regulatory authorities, county administrative boards and municipalities and maintain close contact with the organizations that wish to participate in the siting process. This is done by participation in the consultations that take place on a regional level in concerned municipalities and by participation in the seminar activities that have been conducted in some of the feasibility study municipalities.

Regionally, the county administrative boards in Kalmar, Södermanland and Uppsala counties have, in accordance with the Government's decision (18 May 1995), coordinated contacts between SKB, municipalities and regulatory authorities. This has been done via regular information and consultation meetings with the participation of e.g. SKB, SKI, SSI, the National Coordinator/Special Advisor and concerned municipalities and county administrative boards. Several meetings are held per year in each region.

2. Consultation in conjunction with the integrated accounting

SKB started work on the integrated accounting in the autumn of 1999 when all statements of comment on RD&D-Programme 98 had been received, and while awaiting a decision by the Government. After the Government decision of 24 January 2000, SKB described its plans for the accounting and the consultation in a letter (dated 16 March 2000) to the authorities, county administrative boards and municipalities. The letter described the planned content and background material for the integrated accounting and a timetable.

In the consultation procedure, SKB has primarily made use of the forms for information, consultation and discussion that were developed during the feasibility study work.

Meetings have been held regularly (and minutes kept) with SKI and SSI, and with KASAM. The purpose has been to go through the statements of comment from authorities and clarify their contents, and to present and get viewpoints on SKB's planning and ongoing study work. The contents of the reporting, and the structure of the improved system analysis, have been important discussion points.

Since the early autumn of 1999, SKB has also continuously informed county administrative boards and municipalities of its plans for the integrated accounting, for example at EIA meetings under the auspices of the county administrative boards, and at an EIA seminar on 8–9 September 1999.

At meetings under the auspices of the county administrative boards, SKB has regularly included an item on the agenda about SKB's planned integrated accounting. On these occasions, the work situation has been described and viewpoints and proposals from the discussion have been solicited and recorded. Offered viewpoints have been replied to either directly at the meeting or at the following meeting.

SKB has made itself available for additional presentations and discussions at the request of the consultation parties. This has meant that the integrated accounting work has also been described at public information meetings with municipal reference groups and in some cases also at information occasions for the municipal council.

The most important questions and viewpoints brought up during the consultations are presented in brief below, with an account of how they have been acted on.

3. Presentation of method selection

The structure of SKB's presentation of the method selection, with appurtenant background reports, has been discussed with SKI and SSI in particular. The purpose has been to go through the viewpoints these authorities have voiced in their statements on RD&D-Programme 98. This has also included questions regarding terminology and a suitable structure of the presentation.

The most prominent municipal viewpoint in the method question has been to underscore the importance of a clear account from SKB regarding how different alternative methods have been evaluated and a clear standpoint on this account on the part of the authorities.

The consultation procedure described above has led SKB to place a great emphasis on pedagogical clarity in the account of method selection. The desire of the municipalities to obtain the authorities' judgements of the method and its safety before deciding whether to participate in a site investigation will be able to be met, since SKB's account is now being reviewed by the authorities. SKI has already compiled its own and others' review of SR 97, see Chapter 7. SKI will review the account of the method that is given in the background reports to this report. The results of this review are expected to be ready in June 2001.

4. Site selection

In the consultation regarding the account of site selection, SKI and SSI have emphasized the importance of giving a clear account of the reasoning and argumentation for the selection of sites. A question that has been brought up by regulatory authorities, municipalities and county administrative boards alike has been how different aspects on site selection are weighed together in the selection process. SKB has taken these viewpoints into consideration in the formulation of Chapters 10, 11 and 12 in this report.

Oskarshamn Municipality has underscored the importance of SKB's specifying as clearly as possible where within the designated priority area in Oskarshamn SKB wishes to initiate site investigations if Oskarshamn/Simpevarp is selected for site investigations. SKB gives an account of this in the feasibility study's final report and Chapter 14 in this report.

Several municipalities have expressed the viewpoint that test drilling should be done on more than two sites, and in some cases they have said that initial test drilling should be done in all areas of interest from the feasibility studies. SKB has weighed in the need for sufficient breadth of the selection that is now being done of investigation sites but does not consider it warranted to initiate investigations on more sites than has been proposed in this report. The choice of the number of sites is a compromise between the need for continued breadth in the programme and the need for a narrower focus in view of resources, available competence and the local involvement and potential disturbance which each investigation entails. Furthermore, SKB believes that even if a number of initial boreholes on a site greatly enhance knowledge of the conditions at depth, it will not be possible afterwards to rank the sites as long as the evaluation requirements are satisfied.

The municipalities of Tierp and Hultsfred have voiced the opinion that SKB's selection of sites occurs too early in relation to the municipalities' own treatment of the preliminary final report from the relevant feasibility study. According to SKB, the material that is needed to make the integrated evaluation and choice of investigation sites has been adequate for SKB to decide which sites should be investigated. On the other hand, there are indeed a number of viewpoints and questions in the municipalities' statements of comment that need to be responded to before the municipalities can arrive at a standpoint of their own in the autumn of 2001. SKB intends during 2001 to consult with each concerned municipality and assemble whatever material beyond this report they may need to make a decision on a site investigation. In this way we want to make sure that all viewpoints from a municipality are responded to and have been taken into account by SKB before it is time for the municipality to arrive at a decision regarding a continuation.

At a meeting of EIA Dacke on 31 March 2000, a question was put forward as to whether participation in a site investigation entails an obligation to proceed to detailed characterization. SKB responded that this is not the case. A siting permit must be applied for prior to detailed characterization and construction, and the municipality must then approve. SKB bases the entire process on voluntary participation.

Both authorities and municipalities have asked for SKB's plans for the final repository for long-lived low- and intermediate-level waste, and its relationship to the deep repository. This is described in Chapter 2, where it is said that the question of siting of the repository will not arise for another 30 years or so. This means that the siting process which the municipalities are now participating in is not aimed at a decision on siting of the final repository for low- and intermediate-level waste.

At a meeting of the reference group on 13 March 2000, Östhammar Municipality asked how the site selection process is to be conducted, i.e. what measures are intended to be taken and what the timetable is up to a decision on sites for site investigations. SKB replied at the meeting, and an account of the entire siting process is provided in Parts III and IV of this report.

5. Site investigations

Several municipalities have asked for clear site evaluation criteria with prestipulated requirements that must be satisfied and conditions that would cause a site to be abandoned. Since then, SKB has, in accordance with RD&D-Programme 98, given a detailed account of the requirements made by the deep repository on the rock and thereby also the conditions that can occasion discontinuation of the investigations on a site, see Chapter 13.

The municipalities in Northern Uppland have maintained that they view the question of a deep disposal system as something of importance for the entire region, regardless of where the various facilities end up being built. They have therefore required a regionally oriented and coordinated programme for the site investigation phase in Northern Uppland. SKB presents this in Chapter 14 of this report.

The municipalities have asked for clarification as to when the consultation procedure defined by the EIA provisions in the Environmental Code will start. SKB has responded that the intention is to build further on the consultation forms that have been established during the feasibility studies, and to notify the matter for early consultation in keeping with the provisions of the Environmental Code. Such a notification will lead to a decision for extended consultation according to the Environmental Code by the concerned county administrative board. SKB intends in early 2001 to bring up the matter of time and forms for a notification with the county administrative board in Kalmar County and Oskarshamn Municipality, as well as with the county administrative board in Uppsala County and the concerned municipalities in Northern Uppland. See further Chapters 13 and 14.

In its report number 99-15, SKB has stated that:

> "According to Chapter 6, Section 4–5 of the Environmental Code and the EIS Ordinance (SFS 1998:905), a formal procedure with extended consultation with environmental impact assessment shall be initiated by a decision of the concerned county administrative board when SKB notifies its intention to prepare a siting application for a facility for management or disposal of spent nuclear fuel in a municipality within the county. In SKI's opinion, this should be interpreted as meaning that this extended consultation should be initiated when SKB commences site investigations, since the purpose of these investigations is to prepare a siting application for one of the municipalities."

SKB finds that this is in accord with SKB's described planning.

Several municipalities have also asked if an EIS is needed for the site investigations. SKB has replied to the questions at the meetings, and an account is given in Chapter 13. A notification will be made by SKB to concerned county administrative boards in accordance with Chapter 12 of the Environmental Code for activities not requiring a permit and to the municipality and its environmental office.

The question of lowering of the groundwater table due to investigations or deep repository construction has also been brought up locally, not least in Nyköping. As a consequence, SKB has written a special report on groundwater movements and groundwater lowering in conjunction with the construction and operation of a deep repository /4/.

Another question that is often raised on the local plane regarding the site investigation phase is how landowners and nearby residents will be affected by the planned activities. This has occasioned SKB to hold special information meetings for nearby residents in the areas in question and to frame a document on basic policy in these matters. This policy document was adopted by the board of SKB on 22 November 2000 and will serve as a basis for all future information and consultations with concerned landowners and nearby residents.

6. Meetings

The meetings at a national level, with regulatory authorities and KASAM, and at a regional level are listed in the following tables. Minutes or notes from the meetings are available from SKB, the authorities or, in the case of the regional meetings, the relevant county administrative boards.

Table 1. Meetings at a national level, autumn 1999 and 2000

Date	Topics	Participants, aside from SKB
8-9 Sept. 1999	EIA seminar arranged by SKB	Finnish Ministry of Trade and Industry, Posiva Oy, SKI, SSI, KASAM, Special Advisor, KTH, Dept. of Environmental Law, Alrutz Advokatbyrå, County Administrative Board in Kalmar County, County Adminis trative Board in Uppsala County, Älvkarleby Municipality, Östhammar Municipality, Tierp Municipality, Nyköping Municipality, Oskarshamn Municipality, Hultsfred Municipality
8 Oct. 1999	RD&D 98 supplement, review of SR 97, final repository for LILW	SKI
25 Oct. 1999	Review of SR 97, feasibility studies	SKI
29 Oct. 1999	Comparative system analysis, system analysis of the KBS-3 method, the zero alternative	SKI, SSI
3 Nov. 1999	Site investigations - siting factors, requirements and criteria (minutes not kept)	KASAM
23 Nov. 1999	Siting of the deep repository, EIA, the final repository for long-lived LILW	SKI
26 Nov. 1999	Siting of the deep repository, EIA	SKI
14 Dec. 1999	RD&D 98 supplement, review of SR 97, the final repository for long-lived LILW	
17 Dec. 1999	Comparative system analysis, system analysis of the KBS-3 method, the zero alternative	SKI, SSI
20 Dec. 1999	RD&D 98 supplement, review of SR 97	SKI, SSI
27 Jan. 2000	Comparative system analysis, analysis of the KBS-3 method	SKI, SSI
28 Jan. 2000	Planning for the final repository for long-lived LILW	SKI, SSI
3 Feb. 2000	Comparative system analysis, system analysis of the KBS-3 method	SKI, SSI
30 March 2000	Siting of the deep repository	SKI
7 April 2000	RD&D 98 supplement, long-term plan	SKI, SSI
14 Sept. 2000	Method selection, KBS-3, Technology development	SKI, SSI, KASAM, Special advisor
10 Oct. 2000	Exchange of information	Special Advisor, Ministry of the Environment, Nat. Board of Housing, Building and Planning, Swedish EPA, SKI, SSI, KASAM, Älvkarleby Municipality, Östhammar Municipality, Tierp Municipality, Nyköping Municipality, Oskarshamn Municipality, Hultsfred Municipality, SKB (part of meeting)
20 Oct. 2000	Review of SR 97, RD&D 98 supplement	SKI

Table 2. Regional consultation meetings, autumn 1999 and 2000

Date	Meeting
25 Aug. 1999	Regional consultation, Södermanland County
3 Sept. 1999	EIA Forum, Kalmar County
29 Oct. 1999	EIA Forum, Kalmar County
3 Dec. 1999	Regional consultation, Uppsala County
16 Dec. 1999	EIA Dacke, Kalmar County
17 Dec. 1999	EIA Forum, Kalmar County
10 Feb. 2000	Regional consultation, Uppsala County
18 Feb. 2000	EIA Dacke, Kalmar County
10 March 2000	EIA Forum, Kalmar County
31 March 2000	EIA Dacke, Kalmar County
19 May 2000	Regional consultation, Uppsala County
24 May 2000	Regional consultation, Södermanland County
14 June 2000	EIA Dacke and EIA Forum, Kalmar County
8 Sept. 2000	EIA Dacke, Kalmar County
22 Sept. 2000	EIA Forum, Kalmar County
13 Oct. 2000	Regional consultation, Uppsala County
13 Nov. 2000	Regional consultation, Södermanland County

Table 3. Additional meetings at regional level, autumn 1999 and 2000

Date	Meeting	Participants
10 Dec. 1999	Meeting on account of feasibility studies in Oskarshamn and Hultsfred municipalities	SKI, SSI, Special Advisor, National Road Administration, County Administrative Board in Kalmar County, University College of Kalmar, Metria Hultsfred, municipalities: Emmaboda, Hultsfred, Mönsterås, Nybro, Oskarshamn, Vimmerby, Västervik
21 Sept. 2000	Reference group for inquiries in connection with the review of SKB's supplement to RD&D-Programme 98	SKI, SSI, Östhammar Municipality, Tierp Municipality, Älvkarleby Municipality, Nyköping Municipality, Oskarshamn Municipality, Hultsfred Municipality, Karinta-konsult

Table 4. Participants in regional consultation - Uppsala County

Participants
County administrative board in Uppsala County*
National Coordinator/Special Advisor*
SKI*
SSI*
KASAM
NUTEK
Swedish Maritime Administration
National Energy Administration
S1/Fo 47
Östhammar Municipality*
County administrative board in Stockholm County
County administrative board in Gävleborg County
County administrative board in Västmanland County
County administrative board in the County of Åland
Åland County Council
Tierp Municipality*
Älvkarleby Municipality*
Heby Municipality
Håbo Municipality
Uppsala Municipality
Gävle Municipality
Norrtälje Municipality
SKB*

* Participates regularly.

Table 5. Participants in regional consultation - Södermanland County

Participants
County administrative board in Södermanland County
National Coordinator/Special Advisor
SKI
SSI
KASAM
County administrative board in Stockholm County
County administrative board in Östergötland County
Swedish Maritime Administration
Nyköping Municipality
Oxelösund Municipality
Trosa Municipality
Gnesta Municipality
Flen Municipality
Katrineholm Municipality
Nature Conservation Society in Södermanland County
Nature Conservation Society in Southern Södermanland
SKB

Table 6. EIA Forum - Kalmar County

Permanent participants	Temporary participants
County administrative board in Kalmar County	KASAM
National Coordinator/Special Advisor (co-opted)	OKG Aktiebolag
SKI	Hultsfred Municipality
SSI	
Oskarshamn Municipality	
SKB	

Table 7. EIA Dacke - Kalmar County

Permanent participants	Temporary participants
County administrative board in Kalmar County	Oskarshamn Municipality
National Coordinator/Special Advisor	Hultsfred Municipality
SKI	
SSI	
Hultsfred Municipality	
SKB	

Meetings at local level

A list of meetings at the local level is given in the final reports for the different feasibility studies /5 to 10/.

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/2/ **SKB**
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EIA seminar, 8–9 September 1999. SKB's notes of meeting 14 September 1999. Aggeryd I

/4/ **Axelsson C-L, Follin S, Koyi S**
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/5/ **SKB**
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/6/ **SKB**
Förstudie Nyköping. Slutrapport
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/7/ **SKB**
Förstudie Oskarshamn. Slutrapport
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/8/ **SKB**
Förstudie Tierp. Preliminär slutrapport
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/9/ **SKB**
Förstudie Älvkarleby. Preliminär slutrapport
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/10/ **SKB**
Förstudie Hultsfred. Preliminär slutrapport
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