RD&D-Programme 98

Treatment and final disposal of nuclear waste

Programme for research, development and demonstration of encapsulation and geological disposal

September 1998

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

RD&D-Programme 98

Treatment and final disposal of nuclear waste

Programme for research, development and demonstration of encapsulation and geological disposal

September 1998

Foreword

The Nuclear Activities Act requires a programme for the comprehensive research and development and other measures that are required to manage and dispose of nuclear waste in a safe manner and to decommission and dismantle the nuclear power plants. To meet this requirement, SKB is now presenting RD&D-Programme 98.

RD&D
Research, Development and Demonstration

The programme provides a basis for the safety work and for evaluating and judging different methods for taking care of the nuclear fuel. SKB's plan is to implement deep disposal of the fuel in an initial stage, while holding open the option of using other alternatives. In the RD&D-Programme we describe our activities and planning for this line of action. The review of the programme can offer valuable viewpoints from the outside. Regulatory authorities and the Government can clarify how they look upon different parts of the programme and stipulate guidelines for the future. Municipalities and other stakeholders can, after studying the programme, offer their viewpoints to SKB, the regulatory authorities or the Government.

A concrete interim goal in our plan for implementing deep disposal is to be able to choose at least two sites for site investigations by 2001. Achieving this goal puts heavy demands on SKB, but also other parties:

- SKB must present a body of material of high quality and work in an open and clear fashion.
- The regulatory authorities and the Government should make clear their views regarding SKB's main method, i.e. deep disposal in accordance with KBS-3. Based on the analysis of various methods we have now completed, it should be possible to take a clear stand on whether the method chosen by SKB represents the right strategy.
- Concerned municipalities and regions must be given the resources to enable them to participate fully in the siting process, participate in discussions and safeguard their interests.

In support of coming siting applications for an encapsulation plant and a deep repository, SKB will prepare environmental impact statements (EISs) based on environmental impact assessments (EIAs). EIA consultations have been initiated locally, regionally and nationally. In this context we view the RD&D-Programme and its subsequent review as a part of the EIA work.

Stockholm, September 1998

Swedish Nuclear Fuel and Waste Management Company

Peter Nygårds
President

Claes Thegerström
Executive Vice President
in charge of Siting

Reading instructions

RD&D-Programme 98 is intended to provide an overview of SKB's activities and plans. The detailed research programme is presented in a separate background report. In parallel with RD&D-Programme 98, SKB is publishing a number of reports that provide a more thorough background and a more detailed account, particularly on those issues that the Government mentioned in its decision regarding RD&D-Programme 95.

The programme is divided into two parts: Background and Execution. The background part begins with a chapter on the basic premises (Chapter 1). It deals with general principles, laws and the properties of the waste. The facilities that exist today for dealing with the nuclear waste are also described in the introductory chapter. The two following chapters have to do with the choice between different methods for disposing of nuclear waste (Chapter 2) and with the KBS-3 method, which SKB has chosen as its main alternative (Chapter 3). These two chapters provide a broader account of both the KBS-3 method and different alternative methods than previous RD&D-programmes. The background part concludes with a chapter about the long-term safety of the deep repository (Chapter 4).

The second part, Execution, begins with an overview of SKB's strategy and the main features of the programme, both for the next few years and farther in the future (Chapter 5). The plans for siting (Chapter 6), technology (Chapter 7) and safety assessment (Chapter 8) are then presented in greater detail. This is followed by an overview of our plans for supportive research and development, including continued R&D on other methods than the KBS-3 method (Chapter 9). The programme concludes with a chapter on decommissioning of nuclear facilities (Chapter 10).

An important part of the ongoing and planned work is consultation on environmental impact assessments (EIAs). A first draft of the contents of future environmental impact statements (EISs) is therefore provided in an appendix. By attaching it to RD&D-Programme 98, SKB wishes to give all reviewing bodies an opportunity to offer their viewpoints at an early stage on what future EISs are to include.

Structure of RD&D-Programme 98

RD&D-Programme 98
Background
Execution

Background report
Detailed programme for research and development

Main references

- System account R-98-10
- Alternative methods R-98-11
- Criteria for site evaluation R-98-20
- North-south/Coast-interior R-98-16

Other references

- County general siting studies
- Feasibility study reports
- Other SKB reports
- Research results and investigations from other organizations

Abbreviations

BIOMOVS	Biosphere Model Validation Study
BIOMASS	Biosphere Modelling and Assessment
BWR	Boiling Water Reactor
CLAB	Central Interim Storage Facility for Spent Nuclear Fuel
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EQUIP	Evidence from Quaternary Infills for Palaeohydrogeology
FEBEX	Full-scale Engineering Barriers Experiment in Crystalline Host Rock
GPS	Global Positioning System
HRL	Hard Rock Laboratory
ILW	Intermediate-level waste
LILW	Low and intermediate-level waste
LLW	Low-level waste
HLW	High-level waste
HRL	Hard Rock Laboratory
IAEA	International Atomic Energy Agency
KASAM	Statens råd för kärnavfallsfrågor (Swedish National Council for Nuclear Waste)
KBS	Kärnbränslesäkerhet = Nuclear Fuel Safety
KTH	Kungliga Tekniska Högskolan (Royal Institute of Technology)
MLH	Medium Long Holes
MSEK	Millions of Swedish kronor
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
OECD	Organization for Economic Cooperation and Development
PAGEPA	PAlaeohydrogeology and GEoforecasting for Performance Assessment
PWR	Pressurized Water Reactor
P&T	Partitioning and Transmutation
RD&D	Research, Development and Demonstration
REX	Redox Experiment on detailed scale
RPV	Reactor Pressure Vessel
RVS	Rock Visualization System
SAFE	Safety Assessment of Final Repository for Radioactive Operational Waste
SEK	Swedish kronor
SFR	Final Repository for Radioactive Operational Waste
SGU	Geological Survey of Sweden
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Co)
SKI	Statens kärnkraftinspektion (Swedish Nuclear Power Inspectorate)
SKN	Statens kärnbränslenämnd (National Board for Spent Nuclear Fuel)
SSI	Statens strålskyddsinstitut (National Radiation Protection Institute)
SFR	Final repository for radioactive operational waste
TRUE	Tracer Retention Understanding Experiments
TBM	Tunnel Boring Machine
TDS	Total Dissolved Solids
VDH	Very Deep Holes
VLH	Very Long Holes
VSP	Vertical Seismic Profiling
ZEDEX	Zone of Excavation Disturbance Experiment

Contents

		Page
Summary		11

Part I - Background

1	**Premises**	27
1.1	Waste	27
1.2	What does the law say?	28
	1.2.1 Division of responsibility	28
	1.2.2 Financing	29
	1.2.3 Rules for licensing	30
	1.2.4 Regulations concerning safety and radiation protection	31
1.3	Previous decisions	31
1.4	Existing facilities	32
	1.4.1 Final Repository for Radioactive Operational Waste, SFR	32
	1.4.2 Central Interim Storage Facility for Spent Nuclear Fuel, CLAB	32
	1.4.3 Transportation system	32
1.5	Knowledge base	34
1.6	What remains to be done?	34
2	**Method selection**	35
2.1	Three principles for management of hazardous waste	35
2.2	Different modules in waste management	36
	2.2.1 Supervised storage – interim storage	37
	2.2.2 Geological disposal	38
	2.2.3 Ultimate removal	40
	2.2.4 Reprocessing and recycling	40
	2.2.5 Transmutation	41
2.3	Selecting a main alternative	42
	2.3.1 Two main questions	42
	2.3.2 Aspects of the problem	43
	2.3.3 Four possible strategies	43
2.4	The Swedish main alternative	45
2.5	Historical background	46
	2.5.1 Overview	46
	2.5.2 Chronological summary of important inquiries	47
3	**Deep disposal method**	53
3.1	Planned deep disposal system	53
	3.1.1 Waste	53
	3.1.2 CLAB	54
	3.1.3 Encapsulation plant	54
	3.1.4 Deep repository	54
3.2	System analysis	55
	3.2.1 Safety	56
	3.2.2 Freedom of choice	57
	3.2.3 Long-term storage in CLAB – the zero alternative	58
	3.2.4 Safeguards and physical protection	58
4	**Safety**	59
4.1	Safety principles for a deep repository	59
4.2	Isolation – the primary function of the repository	60
4.3	Retardation – the secondary function of the repository	60
4.4	Safety assessments	62

Part II - Execution

5	**Programme overview**	65
5.1	What does SKB want?	65
	5.1.1 Method	65
	5.1.2 Timetable	65
	5.1.3 Siting	66
	5.1.4 Democratic consensus and community support	66
	5.1.5 Research, development and demonstration	66
5.2	Goals of the work of the next few years	67
5.3	How will SKB achieve its goals?	68
	5.3.1 Siting and establishment	68
	5.3.2 Technology for encapsulation and deposition	72
	5.3.3 Safety assessment	75
	5.3.4 Research	75
5.4	Environmental impact assessments and statements	76
5.5	Resources	77
	5.5.1 Work forms	77
	5.5.2 Organization	78
	5.5.3 Costs	78
6	**Siting**	79
6.1	Overview	79
	6.1.1 Review and commentary of RD&D-Programme 95	80
	6.1.2 Government decisions regarding the siting process	80
	6.1.3 National coordination	81
	6.1.4 Public opinion	81
6.2	EIS document and EIA consultations	82
	6.2.1 EIS document	82
	6.2.2 EIA consultations at different levels	83
	6.2.3 National EIA consultation group	84
	6.2.4 Regional EIA consultation groups	84
	6.2.5 Local EIA consultation groups	85
6.3	General siting studies and feasibility studies	86
	6.3.1 County-specific general siting studies	86
	6.3.2 North-south/Coast-interior	89
	6.3.3 Feasibility studies	93
	6.3.4 Programme for future work	101
6.4	Choice of areas for site investigations	101
	6.4.1 Regulatory body opinions prior to site selection	101
	6.4.2 Available and planned supporting material prior to site selection	102
	6.4.3 Screening procedure	103
	6.4.4 Examples of evaluation grounds	105
6.5	Site investigations and site evaluation	107
	6.5.1 Geoscientific site investigations	107
	6.5.2 Experience from site investigations	108
	6.5.3 Geoscientific site evaluation	109
	6.5.4 Programme for future work	110
6.6	Criteria for site evaluation	110
	6.6.1 Terms and definitions	110
	6.6.2 Requirements and preferences regarding repository performance	112
	6.6.3 Geoscientific evaluation factors	113
	6.6.4 Programme for future work	115
6.7	Instrument and method development for site investigations	116
	6.7.1 Surface geophysics	116
	6.7.2 Position measurement	116
	6.7.3 Drilling technology and measurements during drilling	117

	6.7.4 Methods for hydraulic tests and groundwater chemistry	117
	6.7.5 Borehole geophysics and rock stress measurements	117
	6.7.6 Data management and quality assurance	118
7	**Technology**	119
7.1	Fundamental technical requirements	119
	7.1.1 Requirements on the canister	119
	7.1.2 Requirements on the buffer	120
	7.1.3 Requirements on the bedrock	121
	7.1.4 Requirements on the backfill material	121
	7.1.5 Requirements on the seals	121
7.2	Canister design	122
	7.2.1 Design premises	122
	7.2.2 Canister design	123
	7.2.3 Programme for future work	124
7.3	Encapsulation and transport to the deep repository	125
	7.3.1 Fabrication of canisters	125
	7.3.2 Encapsulation plant	126
	7.3.3 Buffer storage of filled canisters	130
	7.3.4 Transport to the deep repository	130
	7.3.5 Programme for future work	131
7.4	Design and development of the deep repository	131
	7.4.1 Design	132
	7.4.2 System studies	134
	7.4.3 Technology development	135
	7.4.4 Programme for future work	139
7.5	Possible retrieval of deposited canisters	141
	7.5.1 Retrieval from the deep repository	141
	7.5.2 Transport of retrieved canisters	142
	7.5.3 Buffer storage of canisters	142
	7.5.4 Programme for future work	143
7.6	Full-scale testing of technology	143
	7.6.1 Trial fabrication of canisters	143
	7.6.2 The Canister Laboratory	146
	7.6.3 Boring of deposition holes	148
	7.6.4 Testing of deposition machine	148
	7.6.5 Testing of backfilling methods	149
	7.6.6 Testing of retrieval	150
8	**Safety assessments**	151
8.1	What is a safety assessment?	151
8.2	System description	152
8.3	Analysis of different scenarios	153
8.4	Choice of scenarios	154
8.5	Deficiencies in the underlying information	155
8.6	The safety assessment as a prioritizing instrument	156
8.7	Programme for future work	156
	8.7.1 Safety Report 97, SR 97	156
	8.7.2 Evaluation of SR 97	157
	8.7.3 Further development of SR 97	157
8.8	Future safety assessments	158
9	**Research**	159
9.1	Reporting of the research programme	159
9.2	Scope and priorities	159
9.3	Overview of research areas and research programmes for the deep repository	162
9.4	Research on alternative methods	177

10 Decommissioning 183
10.1 Experience of decommissioning 183
10.2 Decommissioning procedure 183
10.3 Current state of knowledge 185
10.3.1 Sweden 185
10.3.2 Other countries 186
10.3.3 OECD/NEA 186
10.3.4 EU 187
10.3.5 IAEA 187
10.4 Programme for future work 188

References 189

Appendix 199

Summary

During the next few years, SKB will add the results of county studies and additional feasibility studies to the background data for siting of the deep repository. We plan to be able to choose at least two sites for site investigations in 2001. The investigations, which will include test drillings, should be able to be started in 2002. An important milestone will thereby be passed in the siting work.

The technology for deep disposal will be tested on full scale at our laboratories in Oskarshamn. At the Canister Laboratory, which will be commissioned in the autumn of 1998, SKB will further refine the technology for sealing copper canisters and verifying their quality. At the Äspö HRL (Hard Rock Laboratory), we will develop and test the technology for handling and depositing canisters, backfilling deposition tunnels, and even retrieving deposited canisters. All of this will be carried out on full scale and in a realistic environment, but without radioactive material in the canisters.

A new safety assessment, SR 97, will be completed in 1999 and then subjected to international scrutiny in accordance with a Government decision. When SKB then receives data from the investigation sites, the safety assessment will be updated and deepened. The research will be focused on the needs of the safety assessment and on providing a basis for following and judging the development of alternative methods such as transmutation.

The programme presented here by SKB is based on the previous programmes, in particular RD&D-Programme 92 with 1994 supplement, and RD&D-Programme 95. Another premise is the commentaries on these programmes and the guidelines laid down by the Government in its decisions. SKB's continued work is based on the following plan:

- A step-by-step programme for implementing deep geologic disposal of encapsulated spent nuclear fuel (demonstration deposition).
- A continued active programme for research and development around central issues relating to technology and safety for the deep disposal method and for alternative methods.

SKB wants to

- Demonstrate deep disposal concretely
- Proceed step-by-step
- Conduct further research
- Keep the door open to change

It will take at least 40–50 years to carry out all measures needed to dispose of all long-lived and high-level nuclear waste in a safe manner. It is therefore appropriate to proceed in steps and keep the door open for technological development, changes and possibilities for retrieving already deposited waste, see Figure 1. This will ensure freedom of choice for the future while at the same time demonstrating the deep disposal method on a full scale and under actual conditions. Decisions regarding siting, construction and operation of an en-capsulation plant and a deep repository will also be taken in steps and based on progressively more detailed information.

The programme for concrete implementation of deep disposal is in an initial phase. SKB has been working for some years now on gathering the supporting documentation that is needed to apply for a siting permit for an encapsulation plant and the initial stage of a deep repository.

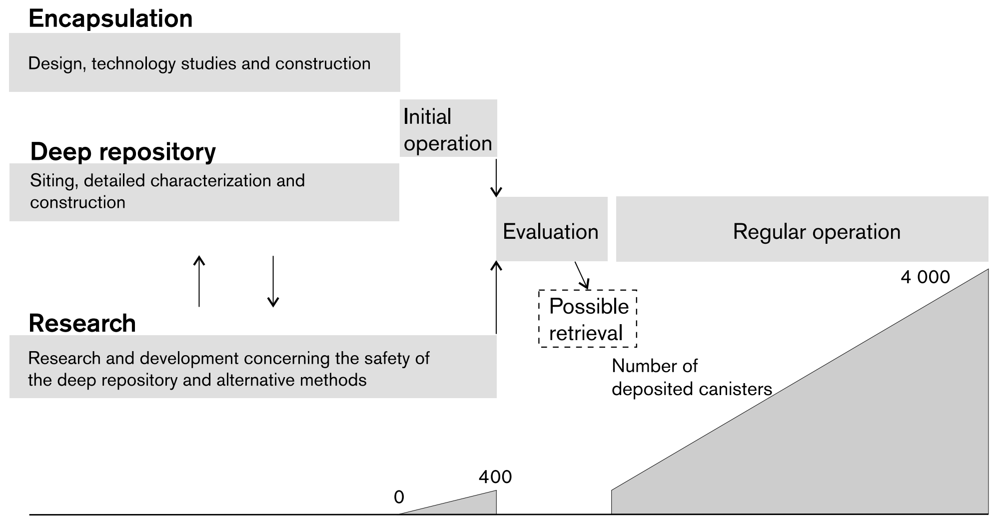


***Figure 1.** Important steps in the deep disposal programme*

SKI
Statens kärnkraftinspektion (Swedish Nuclear Power Inspectorate)

SSI
Statens strålskyddsinstitut (National Radiation Protection Institute)

SKB is responsible for the nuclear waste programme.

SKI and SSI review.

The Government decides.

What are the premises for the nuclear waste programme?

The fundamental guidelines and the division of roles were established long ago. Nuclear waste that is produced in Sweden must also be disposed of in Sweden. It is SKB's responsibility to taken charge of waste management and find a method and a site for final disposal. SKI and SSI review SKB's proposals to make sure they meet the requirements on safety and radiation protection. Permits and licences for siting, construction and operation are issued by the Government, and the municipalities where new facilities are to be built must approve the siting. Money for the activities is set aside in a special reserve fund via a charge levied on the electricity from the nuclear power plants.

Today SKB has a final repository for radioactive operational waste, SFR, and an interim storage facility for spent nuclear fuel, CLAB. In 1997, SKB applied for permission to expand CLAB to permit temporary storage of all fuel from the Swedish nuclear power plants (NPPs). The Government gave permission for the expansion of CLAB in August 1998.

Via the system with SFR, CLAB and the ship M/S Sigyn, SKB is already managing and disposing of the radioactive waste products of nuclear power today. The planning of an encapsulation plant and a deep repository is aimed at establishing a system that increases long-term safety.

What methods are being considered for disposing of the nuclear waste?

The best solution would be if it were possible to utilize the spent nuclear fuel for something useful or remove its radioactivity to eliminate the problem. If this isn't possible, the nuclear waste must be disposed of in such a form and on such a site that it does not escape and harm man or the environment. It is, for example, possible to store the waste in buildings on the ground surface or in repositories in the bedrock.

Several methods and technical solutions for disposing of the nuclear waste are thus conceivable. In its decision on RD&D-Programme 95, the Government requested "...an account of the alternative solutions to the KBS-3 method which SKB has described in previous research programmes or that have been conside-red in international studies." Now SKB is publishing such an account in a special report entitled "Alternative methods. Ultimate disposal of nuclear fuel waste".

Four basically different strategies for management of the spent nuclear fuel can be distinguished:

- ***Supervised storage***
  The spent fuel is kept intact. It is stored indefinitely under controlled conditions, and a decision regarding disposal in accordance with one of the following alternatives is postponed until a later date.
- ***Direct disposal in deep repository***
  After interim storage, the spent fuel is encapsulated and deposited in a deep repository, without the need for supervision or maintenance but with the option of retrieval. The deep repository can, for example, be designed as a system of tunnels with deposition holes (e.g. KBS-3). Deposition can also take place in long tunnels (Very Long Holes) or in boreholes down to a depth of several kilometres (Very Deep Holes).
- ***Reprocessing, possible transmutation, followed by deposition in deep repository***
  Uranium and plutonium are separated (partitioned) by chemical means to be re-used as nuclear fuel. Remaining waste is emplaced in a deep repository. This solution may also include transmutation in the future.
- ***Ultimate removal***
  The spent fuel is rendered inaccessible for all future time, for example by launching into space.

Four strategies
- Supervised storage
- Direct disposal in deep repository
- Reprocessing (transmutation)
- Ultimate removal

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

The different strategies, as well as the technical solutions, may be developed to varying degrees and knowledge about them may vary. The technology for supervised storage, for example, has long been established on an industrial scale. Transmutation technology, on the other hand, is still in the research stage, which means that there are great uncertainties whether it will be able to be established on an industrial scale and, if so, what performance can be achieved.

Supervised storage - established but not long-term safe

Transmutation - at the research stage, future uncertain

Ultimate removal - not realistic

Deep disposal is the main alternative

SKB's overall assessment is that geologic disposal of encapsulated fuel ought to remain the main alternative. Supervised storage on or near the ground surface does not meet the requirements on long-term safety, but is included as an important step in all alternatives for managing and disposing of the spent fuel. Transmutation technology is not available today and contains many uncertainties. Even if transmutation should be developed on an industrial scale, some form of deep repository is needed. However, SKB considers the technology to be interesting enough that we want to continue supporting research and keep track of developments. Conceivable methods for ultimate removal are not technically or politically realistic.

What does the KBS-3 deep disposal method entail?

The plan is that when the nuclear fuel has been stored for about 30 years in CLAB it will be encapsulated in tightly sealed copper canisters. This is done in an encapsulation plant. The canisters are then transported to a deep repository, where they are deposited in bentonite-lined holes in the bottom of tunnels about 500 metres down in the bedrock. The nuclear facilities that will be included in this system are shown in Figure 2.

SKB presents system analysis

In its decision regarding RD&D Programme 95, the Government stipulated that SKB must "carry out a system analysis of the entire final disposal system (encapsulation plant, transportation and final repository)". One purpose was to obtain background data for an overall safety assessment of the entire system.

We have prepared such a system analysis for the KBS-3 deep disposal method. The analysis shows that the system can be designed so that rigorous safety requirements can be met, both in operation of the facilities and in the long term in the deep repository. Work on the system analysis will continue and become increasingly detailed. Among other things, the new safety assessment (SR 97) will provide additional material for the system analysis.

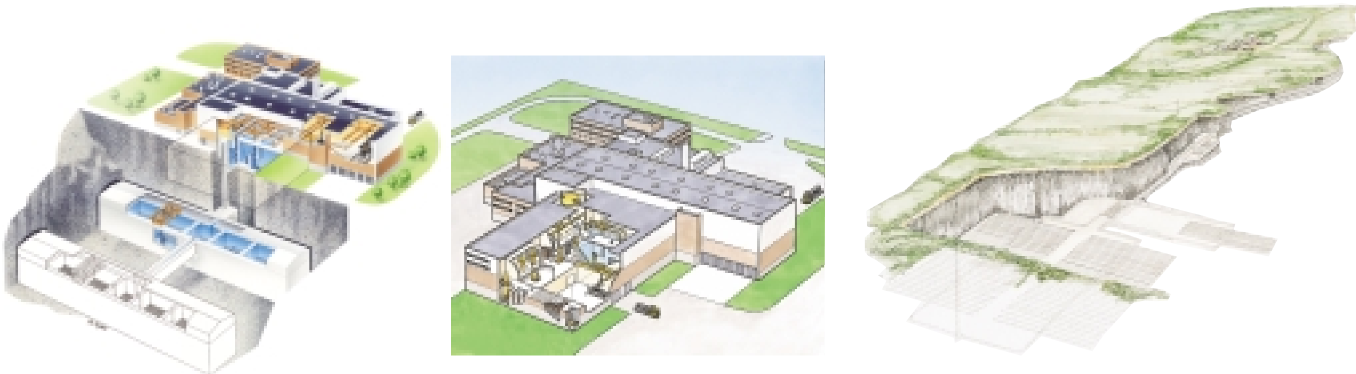


Figure 2. *Nuclear installations in the planned deep disposal system.*

Possible to store for at least 100 years in CLAB

A special question has been how long the fuel can remain in CLAB. Studies show that the storage time can probably be extended to 100 years or more, provided that storage takes place under controlled forms, i.e. with operation and supervision of the facility as today and with maintenance of rock caverns, build-ings and installations. An important prerequisite is that cooling of the fuel be maintained. If CLAB should for some reason (e.g. war) be abandoned and its systems should fail, this could lead to unacceptable releases and doses to the environment.

What is the plan for the rest of the programme?

SKB has examined the advances and setbacks of the past few years and established guidelines for the future programme and a modus operandi. The deep geologic disposal method will be developed and refined so that it can be implemented in practice in an initial stage. We maintain it is the best method for ultimate disposal of spent nuclear fuel. The work should be carried out so that sufficient time is provided for the democratic decision-making process in the affected regions and municipalities and for a thorough EIA process. Somewhere around 15 years is probably needed before encapsulation and deposition can be commenced in an initial stage.

Many steps in licensing process

The road leading up to an ultimate disposal of spent nuclear waste executed in this fashion is long and comprises many steps. Two nuclear installations – an encapsulation plant and a deep repository – need to be sited and built. Figure 3 shows all the remaining steps in the siting and construction of these facilities, operation of the system, closure and supervision. For each facility, and for each of the steps, SKB must apply for permits. Since the facilities are supposed to function in concert, there are also links between the licensing processes. The decisions are made by the Government, and approval must be obtained from the safety, radiation protection and environmental authorities, as well as the concerned municipality, in order for SKB to proceed from one step to the next.

Siting of deep repository is a key question

The siting of the deep repository is a key question in the nuclear waste programme. Without concrete investigations of candidate sites, the programme cannot progress closer to realization. That is why the work of gathering all the background data needed to choose the sites to be investigated will have top priority during the coming years. Conducting further feasibility studies remains an important part of this work. The perspective will be more regional than before.

As far as the encapsulation plant is concerned, SKB sees advantages to a co-siting with CLAB, but it is also possible to locate it adjacent to the deep repository. This possibility will be explored when candidate sites for the deep repository have been chosen. In addition to the nuclear installations, SKB will also establish a factory for fabricating canisters. It can be located in the same region as the encapsulation plant or the deep repository. Alternatively, it can be co-sited with an existing metalworking plant.

SKB plans to build the encapsulation plant at CLAB

The support of the community and a democratic underpinning of all important decisions is required for the realization of the deep repository project. The programme, including the participation of the municipalities in the siting work for the deep repository, needs the clear backing of the government authorities. SKB will therefore continue its efforts to obtain a broad and active consensus in the community on the nuclear waste issue.

The programme needs the support of the community to be realized

What does SKB want to achieve in the next few years?

The most important goal now is to begin site investigations for the deep repository on at least two sites in the country. To achieve this, SKB plans to accomplish the following by 2001:

Two sites are chosen by 2001

- Report the results of regional general siting studies for all counties in Sweden except Gotland.
- Report the results of the feasibility studies in Nyköping, Östhammar, Oskarshamn and Tierp.
- Conduct and report the results of at least one more feasibility study.
- Submit an integrated report of all background data (general siting studies, feasibility studies, comparison material, screening material, etc.) with SKB's choice of sites for site investigations.

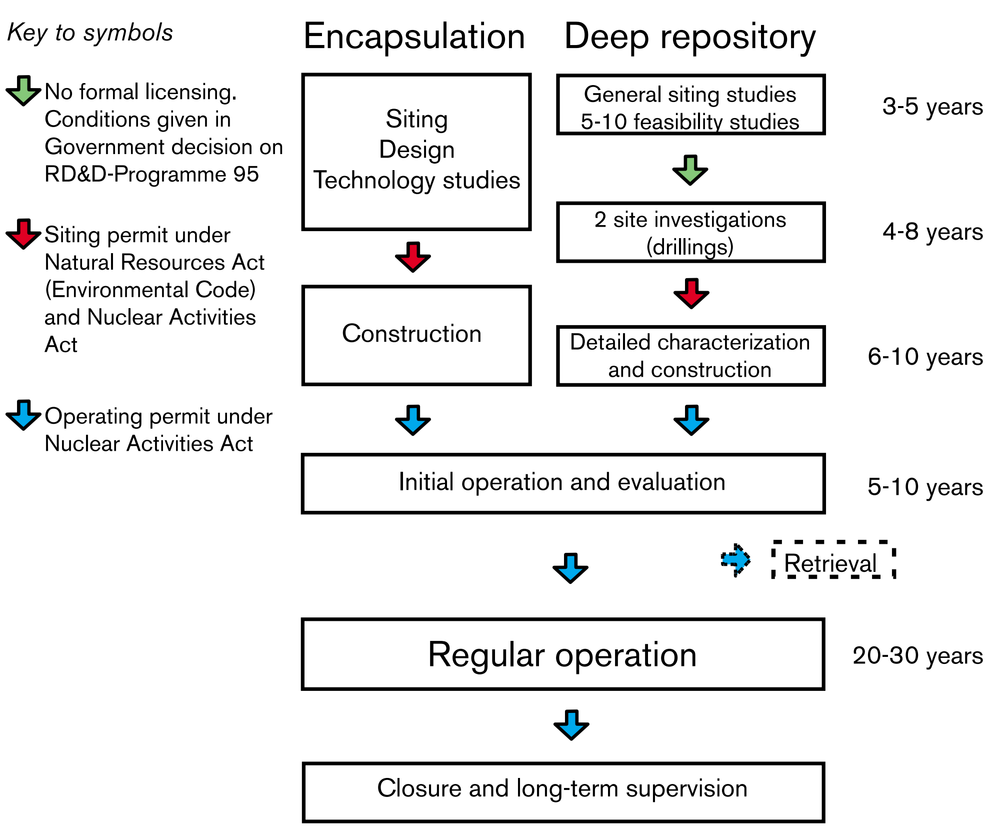


Figure 3. *Step-by-step siting, construction, operation and closure.*

- Present programmes for geoscientific site investigations and site evaluation with criteria.
- Choose at least two sites for geoscientific site investigations and submit site-specific investigation programmes.
- Submit a new comprehensive assessment of long-term safety and have it reviewed by international experts.
- Continue the work of supportive research on the main method and alternative methods for managing and disposing of spent nuclear fuel.
- Continue the work of technology development and planning/design of encapsulation and deep disposal.
- Compile supporting material for an application for a permit to build an encapsulation plant.

How will the siting of the deep repository take place?

Siting of the deep repository began in 1992. At that time an extensive body of data on the bedrock in different parts of the country was already available. This data consisted of the results of general geoscientific surveys and specific studies on some ten or so "study sites" all over the country. Since 1992, general siting studies of the entire country have been performed, along with feasibility studies of individual municipalities.

SGU surveys and assesses the bedrock in each county, except Gotland

Figure 4 illustrates the siting data that is now available on various scales. An important new contribution to the data is the regional general siting studies. The Geological Survey of Sweden, SGU, is going through what is known about the bedrock in all counties, except Gotland, and determining on this scale where suitable bedrock for a deep repository may be located. SKB is supplementing SGU's material with information on infrastructure and land use. During the autumn of 1998 we will publish regional studies for the ten counties situated on Sweden's east coast, and the remaining county studies will be finished in early 1999. So far, regional general siting studies show that there are suitable areas for

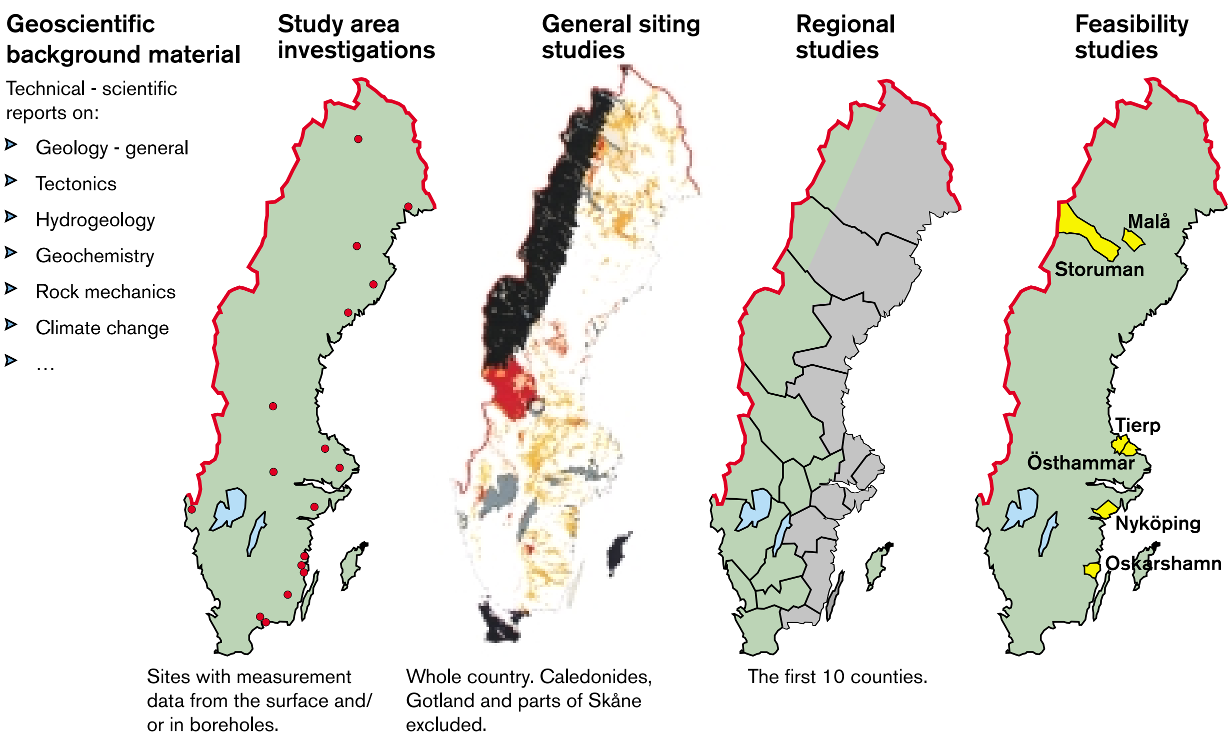


Figure 4. *Siting data on different scales.*

further studies in all studied counties. This provides a basis for determining where within each county it is meaningful to try to proceed with additional surveys and feasibility studies.

A special inquiry into the advantages and disadvantages of siting the deep repository in northern versus southern Sweden, and on the coast versus in the interior, has also been appended to the siting data. This inquiry was requested by the Government in its decision on RD&D-Programme 95. The inquiry clarifies how these geographic aspects can affect the prospects for a siting in different parts of Sweden. The study shows that it is not possible to single out any part of the country as particularly suitable, since local conditions and the properties of the rock at depth are of such great importance.

The concrete work of identifying possible areas for site investigation takes place in the feasibility studies. Unfortunately, as was the case in Storuman, this work will be discontinued in Malå since a referendum in September 1997 resulted in 54% of the voters saying no to allowing SKB to continue siting studies in the municipality. There are many lessons to be learned from Storuman and Malå. We have studied what happened in these municipalities in various ways. Researchers have interviewed residents and local representatives of Malå Municipality as well as people who have been involved on the no and yes sides.

Local referendums:

Storuman (1995)
71 percent no

Malå (1997)
54 percent no

The no side indicated its concern about the disposal method and the transport risks. Furthermore, they believed that tourism and reindeer herding would be negatively affected. Other common arguments were that there is a risk that the deep repository would receive nuclear waste from all of Europe and that the Government can override the municipal veto if the municipality says yes to a site investigation. Another reason mentioned for saying no was that Malå has not benefited in any way from nuclear power.

The yes side underscored the national responsibility and the opportunities for future stable employment and development of the municipality. They believed that a yes to a site investigation was not binding for a definite siting of a deep repository in their municipality. Both the yes and no sides and many others who participated in the discussion called for more active involvement on the part of the Government, the Riksdag and regional bodies.

The feasibility studies in Nyköping and Östhammar have arrived at preliminary final reports that designate a number of potentially interesting areas in each municipality. SKB plans to publish final reports on these two feasibility studies during 1999, after we have obtained viewpoints from the municipalities and other concerned or interested parties. A feasibility study was begun in Oskarshamn in 1997 and is expected to take about 2 years. A feasibility study will get under way in Tierp during the autumn of 1998 and is expected to be concluded during 2000.

Feasibility studies are being conducted in
- Nyköping
- Östhammar
- Oskarshamn
- Tierp

Additional feasibility studies can derive benefit from the experience that has been gained and the methodology that has been tested thus far. Provided that new feasibility studies can be started during 1998–99, selection of at least two sites for site investigations should be able to take place during 2001.

The feasibility studies are being conducted with the wholehearted involvement of the municipalities. The county administrative boards in the concerned counties are participating by arranging forms for regional consultations on environmental impact assessment (EIA). The national coordinator appointed by the Government in 1996 has, at the request of the municipalities, established a national EIA forum where joint discussions are being held on such subjects as alternative methods, system analysis of the deep repository method and the siting process. SKB thinks that this has created much better forms for the siting work and the support to the municipalities than existed a few years ago. Clarification is still needed on some points, however. For example, the government authorities need to clarify the forms and the support for the participation of the municipalities after the feasibility study phase.

Forms for support to municipalities need further clarification

Integrated siting data and criteria for site evaluation are compiled

In preparation for the selection of at least two sites for site investigations, SKB will compile all siting data with, among other things, an integrated evaluation of the feasibility studies and of the comparison material. Furthermore, criteria will be defined for how site investigations are to be evaluated. In this programme we explain what background material will be available, how we plan to go about choosing sites, and the work that is under way to define criteria for site evaluation. The Government mentioned this in its decision on RD&D-Programme 95, and it has also been requested in the EIA consultation groups.

SKB thinks that the authorities need to state their opinions on the choice of sites

The programme for site investigations will be adapted to local conditions on the sites and in the municipalities chosen. In the same way as for a feasibility study, SKB will develop the overall programme for the site investigation phase in consultation with the municipality. In order for municipalities to be able to make a decision regarding a possible site investigation, statements are also needed from the regulatory authorities indicating whether SKB's account of the disposal method, the site investigation programme and the choice of sites is satisfactory.

Within a six-year period, we believe the site investigations will have come a long way and that the work of compiling supporting material for an application to site and build the deep repository on one of these sites will have begun.

How is SKB developing the technology for the deep disposal system?

Tried-and-tested technology exists for management and transport. Encapsulation and deposition are being developed.

SKB has practical experience of managing and transporting spent nuclear fuel and other nuclear waste. The components of the deep disposal system that are new and untested on an industrial scale are encapsulation and deposition of spent fuel. Designing, fabricating, sealing and inspecting canisters is therefore a key area in the programme. Another is how the practical deposition (emplacement) of canisters in the deep repository will take place.

Encapsulation

Before the spent fuel is emplaced in the deep repository, it will be encapsulated in canisters. The canisters will be designed to ensure high safety in encapsulation, transport, deposition and final disposal. Safety in final disposal is what primarily governs the design of the canister. The primary function of the canister in the deep repository is to isolate the spent fuel from the environment. As long as the canister is intact, all dispersal of radioactivity is prevented. The canister is supposed to withstand all known corrosion processes so that it will remain intact in the deep repository for at least 100,000 years. If the canister should nonetheless fail, the other barriers are supposed to retard and attenuate the dispersal of radionuclides to acceptable levels.

SKB has conducted research to study the durability of the copper canister since the end of the 1970s. The research results generally show that the planned canister can meet the requirements. Technical development work is also being carried out to enable canisters to be fabricated on an industrial scale. In recent years, all components of the canister have been trial-fabricated on full scale by means of different methods.

Different methods for canister fabrication will be further developed in the coming years. When a final fabrication method is to be chosen, SKB must have tested and specified all fabrication steps and the system for quality assurance must have been certified according to international standard. Technical documentation for a canister plant must be available.

To meet the need for canisters for full-scale tests at the Äspö HRL, a couple of complete canisters will be fabricated in 1998. At least six more canisters will be fabricated for the same purpose in 1999. Copper tubes and copper lids for the canisters will be fabricated to meet the needs of the Canister Laboratory.

During the next few years, SKB will survey and assess suppliers on the market for the purpose of finding the best suppliers and forging long-term relations with them. SKB plans to implement a quality system that covers the entire chain from material suppliers to deliveries of finished canisters.

In RD&D-Programme 95 we described the plans for building a laboratory for encapsulation technology to develop the central parts of the encapsulation process. Such a laboratory has now been built in Oskarshamn and will start operation in the autumn of 1998, see Figure 5. The Canister Laboratory will serve as a centre for development of encapsulation technology and training of personnel for the encapsulation plant.

The Canister Laboratory is being officially opened in the autumn of 1998

In summary, the plans for development of the encapsulation technology entail that we plan to do the following during the next three years:

- Further develop the technology for sealing and testing of canisters. The programme for the period up to 2001 includes trial sealings and testing of equipment for nondestructive testing of the quality of the welds.
- Test and demonstrate other parts of the encapsulation process in the Canister Laboratory.
- Compile supporting documentation for an application for a permit to build the encapsulation plant.
- Choose a canister fabrication method.

A fabrication method for the canister will be chosen within three years

During the subsequent three-year period, SKB plans to specify in detail how the canister will be designed and fabricated and to apply for a permit to build the encapsulation plant.

Construction of facilities

Previous experience available from construction of the NPPs and CLAB can be drawn on in building the encapsulation plant and the deep repository's surface facilities.

For construction of the deep repository's underground section, SKB has experience from the rock facilities at CLAB, SFR and the Äspö HRL. On some points, it is nevertheless necessary to modify existing technology or develop new technology. This is above all true of methods for building and grouting tunnels to

Figure 5. *Canister Laboratory in Oskarshamn*

meet the requirements on the deep repository, technology for making deposition holes, and methods for describing and predicting rock conditions before and during construction. SKB is conducting technology development around these questions, the results of which will gradually be added to the accumulated planning of the deep repository.

Within the next six years, the site investigations are expected to get under way and progress to a point where the design work can be based concretely on data from the sites being investigated. The goal is to be able to present a general, site-adapted design of the deep repository facilities for the specific sites in question. Before then, schematic solutions will be established for important subsystems, such as the transportation system, access options to the underground facilities, and driving methods for the tunnels.

Deposition of waste

At the deep repository, the canisters will be received and taken down to their respective deposition holes. A large portion of the canister handling can be done using tried-and-tested technology. New technology needs to be developed to transfer the canisters to handling machines in the deposition tunnels and emplace them in deposition holes.

Full-scale trials at the Äspö HRL
- Bore deposition holes
- Deposit and backfill
- Follow course of events after deposition and backfilling
- Retrieve deposited canisters

Buffer and backfill material is also needed in the deep repository. The bentonite buffer must be able to be manufactured and placed in the deposition holes so that it surrounds the canister. Furthermore, the deposition tunnels will be backfilled and, at a later point in time, the entire deep repository closed and sealed. The deposition and backfilling operations are in large parts unique to the deep repository, and the work of developing the technology has been going on for a long time.

The full-scale trials that are now planned at the Äspö HRL entail a new step in the development of deposition and backfilling technology. With these trials, components developed individually so far will be tested in a realistic environment and on a full scale. The Äspö HRL will thereby become the central resource in SKB's work of developing, testing and demonstrating the deep disposal technology. Important tests planned at the laboratory during the coming three-year period are full-scale boring of a number of deposition holes, tests of deposition and retrieval, and trials with backfilling and sealing of tunnels. The evolution of the deep repository after deposition will be simulated in one tunnel section. The deposited canisters will contain electric heaters that simulate the heat flux from the nuclear fuel. The dispersal of heat from the canisters and water uptake and swelling in the surrounding buffer and backfill will be followed for several years.

Development and design of machinery and vehicles is planned in parallel with these trials, Figure 6. The goal is to be able to demonstrate the deposition technology in its entirety within a six-year period.

How will long-term safety be assessed?

New safety assessment 1999

The long-term safety of the deep repository is evaluated in safety assessments. Development of safety assessment has been going on continuously since 1979 when the first safety report was presented (KBS-1). The most recent major assessment (SKB-91) was presented in 1991. SKB is currently carrying out a new safety assessment called SR 97, which will be presented in 1999. It will contain a number of new features compared with previous assessments, of which the most important are:

- A systematic documentation and treatment of the processes that can occur in a deep repository and a new form for describing the entire system of processes.

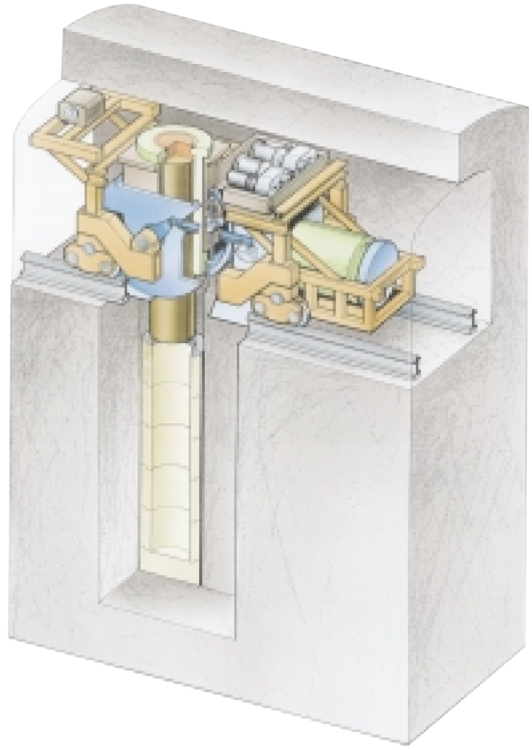


Figure 6. *Schematic diagram of the deposition machine that will be tested at the Äspö HRL.*

- A systematic treatment of deficiencies in numerical data for all processes that directly affect calculations of radionuclide transport.
- Deepened studies of the course of events inside a canister with the assumption of defective copper shell.
- A comparison of three models for water flow and radionuclide transport in the bedrock, based on conditions at Äspö.
- A new method for determining the effects of earthquakes on the repository.

What research is under way and planned?

SKB has been conducting extensive research since the end of the 1970s. The main purpose has been to develop the methods and gather the scientific data needed to assess the long-term safety of the repository. This research has laid the foundation for proceeding with the first stage of a deep repository. This does not mean that the research is over. Continued research can further improve the knowledge base.

The research programme has several goals. The most important is to provide as good a body of material for the safety assessment as possible. The research should also provide material for judging the development of alternative methods. Important topics for continued research include the following:

- *Spent fuel.* The durability of the spent fuel in groundwater was something SKB started investigating in 1977 (KBS project) and the present-day programme was adopted in 1982. Improved knowledge and models are being developed for the safety assessment.
- *Buffer and backfill.* The properties of the bentonite as a buffer between canister and rock are being investigated and an important research area is the stability of the bentonite (chemical and physical).
- *Structural geology and mechanical stability of the rock.* The rock is an important barrier that is supposed to protect the canister. Prior to siting, SKB is improving knowledge of margins in the rock's capacity to isolate the waste. Methods

SKB's research should

- Further improve the knowledge base for the safety assessment
- Provide material for judging alternative methods

Buffer

Material between canister and rock

Bentonite

Clay, usually of volcanic origin

for surveying and interpretation of the structure of the rock are being further refined and more studies are being conducted regarding how earthquakes can affect a deep repository.

Sorption
Uptake of solutes on solid surfaces

- *Water flow and transport*. Solute transport in the rock is dependent on factors such as groundwater flow and flow paths. Measuring the hydraulic properties of the rock in the area where the repository is to be situated and describing them with flow models is important for the safety assessment. Models and measurement methods are being progressively improved. It is also important to study how substances are retained in the rock by sorption on the minerals in the rock. Such experiments are being performed at the Äspö laboratory.
- *Groundwater chemistry*. Deep groundwater is an important part of the chemical environment in the repository. Investigations are being conducted to determine how stable the environment is, how it reacts to the construction of the repository, and what the future may bring.

Microbes
Tiny organisms, e.g. bacteria and virus

Colloids
Particles that are so small they don't sink to the bottom of liquids

- *Radionuclide chemistry*. The chemical properties of radionuclides determine how mobile they are in buffer and rock. The influence of microbes, colloids, gas and pore water in concrete is being investigated.
- *Radioactive substances in the biosphere*. If radionuclides from a repository reach the ground surface, they can be spread in the biosphere. Models and data for calculations of the consequences of a release are being improved.

Natural analogues
Examples from nature of materials and events in the repository

SKB is participating in several EU projects. Two of them aim at learning from natural analogues of deep disposal. One concerns the natural reactors in Oklo, Gabon, and the other involves a uranium ore in Palmottu in southern Finland. The traces of the hydrogeological conditions that previously prevailed in Sweden and other countries are being investigated in two other EU projects. This gives an idea of what variations in water flows may occur and what an ice age may entail.

At Laxemar in Oskarshamn, SKB has drilled a hole for sampling and measurement in the rock down to a depth of 1,700 metres. This has increased knowledge of the rock and the groundwater at great depths.

Long-lived low- and intermediate-level waste, LILW, will also be disposed of in the deep repository. SKB is conducting a project where such waste is being inventoried, the design of the repository developed and long-term safety assessed.

SKB supports research on transmutation

SKB is also conducting research on alternatives to the deep disposal method. We believe that transmutation is a particularly interesting alternative; it is the only known method which could significantly affect the content of radionuclides in the nuclear waste. There is considerable international agreement among nuclear organizations and experts that a successful development of transmutation will not eliminate the need for a deep repository. It can, however, alter the design premises for the deep repository and greatly reduce the quantity of long-lived radionuclides that have to be disposed of. It can affect the size of the deep repository and the design of the engineered barriers. The goals of SKB's research into the transmutation of long-lived radionuclides are as follows:

- Examine how the method can affect waste quantities and nuclide content.
- Determine if, how and when the method can be utilized to simplify, improve or develop the system for final disposal of nuclear fuel waste from the Swedish NPPs.

We also consider it our duty to participate in an appropriate fashion in international projects – especially EU projects – in this field.

What are the plans for the future decommissioning of the NPPs?

Overall responsibility for planning and executing the decommissioning of the nuclear power plants rests with the nuclear power utilities. In this work the utilities can use SKB as a resource. SKB is also responsible for disposing of the radioactive waste from decommissioning.

SKB's development work aims at ensuring that knowledge and technology for decommissioning is available in good time before detailed planning of the decommissioning work is to begin. We keep track of international developments in the field and study experience from modification work at the NPPs.

The timetable for decommissioning of the Swedish NPPs has not yet been determined. It is influenced by such factors as radiation protection aspects and political decisions.

What is especially urgent to obtain viewpoints on?

RD&D-Programme 98 will, like previous programmes, be reviewed by a number of bodies. SKI bears principal responsibility for the review work, and KASAM will issue a special statement of opinion to the Government. The Government can then make decisions regarding conditions for the continued programme.

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

SKB welcomes viewpoints. It is particularly urgent to obtain:

- Clarification on whether deep disposal according to the KBS-3 method will continue to be the preferred method.
- Viewpoints and advice concerning the body of material we are compiling in preparation for the choice of sites for site investigations.
- Viewpoints and advice on what is to be included in future environmental impact statements.

How will future reports be made?

The nuclear waste programme is now in a phase with extensive EIA consultations in concerned municipalities and regions and on a national level. SKB sees RD&D-Programme 98 and its review as a component of the EIA process.

Decisions in conjunction with the siting work, as well as decisions on permit applications, will have to be made at times that may differ from the times for future RD&D-programmes. Practically, this means that the reporting of the background material for siting decisions etc. will be separated from the RD&D-programmes, which can then be focused on the long-term issues and the research on safety and alternative methods.

Part Ⅰ- Background

1 Premises
2 Method selection
3 Deep disposal method
4 Safety

1 Premises

It is now twenty-five years since a coordinated Swedish nuclear waste programme began to take shape. The progress made to date has created the means for today's management of the nuclear waste and for planning ahead. Decisions and guidelines have been affected by the nuclear power debate in Sweden, but also by international policies and decisions regarding principles and methods for dealing with the waste from nuclear power.

There is a clear division of responsibility, with producer responsibility resting with the industry and responsibility for review, regulation and oversight resting with the public authorities. Overall political responsibility rests with the Government and the Riksdag (parliament). The industry's producer responsibility entails that the utilities that produce electricity from nuclear power, and thereby generate nuclear waste, are also obligated to manage and dispose of the waste in a manner that is safe for man and the environment. SKB has been commissioned by the nuclear power utilities to discharge this obligation.

Other factors that determine the way the radioactive waste is dealt with are the chemical and physical properties of the waste and the disposal medium. The state of the Swedish bedrock also affects the disposal prospects.

Today a final repository for LILW (low- and intermediate-level waste), an interim storage facility for spent nuclear fuel, and a transportation system are in operation. To complete the system we need to build an encapsulation plant and a deep repository for the spent nuclear fuel.

1.1 Waste

The power industry in Sweden has been producing electricity by means of nuclear power for more than 25 years. Today approximately half of Sweden's electrical energy is produced in this manner, while most of the remainder comes from hydropower. The operation of the nuclear power plants gives rise to nuclear waste, which includes nuclear fuel. The waste is divided into different categories according to the level of radioactivity (low-, intermediate- or high-level waste) and according to the life of the activity (short- or long-lived waste).

It will take up to 500 years before the radioactivity from short-lived waste has declined to the level that occurs in nature

It will take 100,000 years for the radioactivity from the long-lived waste to fall to the level of naturally occurring uranium

The total quantities of nuclear wastes that must ultimately be disposed of in Sweden are dependent on the number of nuclear reactors and their operating time /1-1/. The waste quantities influence the required capacity of the different waste facilities, but not the fundamental steps needed to dispose of the waste.

The nuclear waste is hazardous because it contains radioactive substances (radionuclides) that disintegrate and emit radiation. The radiation may have a short or a long range. Radiation with such a short range that it doesn't penetrate the skin only causes injury if the radioactive substance enters the body. Human beings can be protected against such radiation by making sure that the radioactive substances do not contaminate the environment, for example via air, food chains or drinking water. A common protective measure is to make the waste poorly soluble in water. This protection is improved if the waste is furthermore enclosed in tightly sealed containers which prevent contact with water or air for a long time.

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 electro-magnetic 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.

If the radiation has a long enough range it can cause injury even if the radiation source is outside the body. The radiation can then enter the body through clothing and skin. It is possible to protect human beings against such radiation by placing and handling the nuclear waste behind radiation shields of e.g. concrete, lead or water.

Spent nuclear fuel is hazardous from both of these aspects. In the short term it is above all the penetrating radiation that requires protection in the form of radiation shielding in different working environments. In the long term, for example in a deep repository, the penetrating radiation declines due to radioactive decay. The protection is therefore designed mainly to prevent substances that emit short-range radiation from contaminating the environment.

More can be read about the radiotoxicity of spent nuclear fuel and how man and the environment can be protected in the short and long term in /1-2/. The long-term chemical properties of the waste, for example the fact that it is very poorly soluble in water, and how they are decisive in determining the design of a deep repository are also described there.

The properties of the nuclear waste are thus such that man and the surrounding environment must be protected against radiation. Firstly, the waste must be kept under control and prevented from being diverted. Secondly, radiation doses to personnel and the public during handling and storage must be limited, along with releases of radioactive materials to the environment.

1.2 What does the law say?

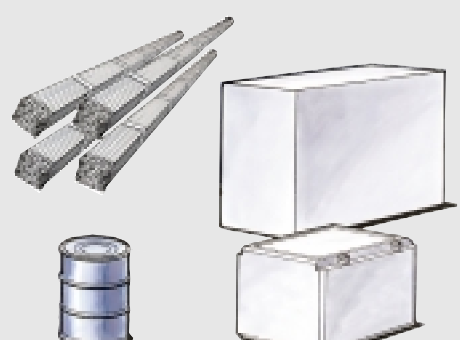
Swedish law regulates the management of nuclear waste in a number of different ways. A clear producer responsibility is expressed in the legislation, which also prescribes how waste management is to be financed. Rules are further stipulated on how licensing of e.g. a deep repository is to proceed, along with detailed requirements on radiation protection and safety for waste facilities.

1.2.1 Division of responsibility

The Swedish legislation places responsibility for the nuclear waste on the producers, while the Government and the Riksdag bear overall responsibility. SKI and SSI scrutinize SKB's proposals to make sure they meet the requirements on safety and radiation protection. The obligations surrounding management and disposal of radioactive waste are defined in the Act on Nuclear Activities, in the Ordinance on Nuclear Activities, in the Act on the Financing of Future Expenses for Spent Nuclear Fuel etc., as well as in certain permits and guidelines issued by the Government.

Estimated waste quantities if all reactors operated for 25 years

Spent nuclear fuel	13,000 m^3
LILW from Studsvik	2,000 m^3
Reactor internals	10,000 m^3
LILW from NPP:s and treatment plants	80,000 m^3
Decommissioning waste	155,000 m^3
Total quantity, approx.	260,000 m^3



The provisions entail that the owners of the nuclear power reactors are responsible for all the measures that are needed in order to manage and dispose of the nuclear waste in a safe manner. This also includes decommissioning and dismantling the nuclear power plants at the end of their service lives, conducting research and development on waste disposal, and studying alternative possibilities. The owners must defray all costs for waste management. A programme describing the activities must be submitted to the authorities every third year.

The companies that own nuclear power plants (NPPs) are Vattenfall AB (Ringhals), Barsebäck Kraft AB, OKG Aktiebolag (Oskarshamn) and Forsmarks Kraftgrupp AB. These companies have delegated responsibility for nuclear waste management from the time the waste leaves the NPPs to the jointly owned company Svensk Kärnbränslehantering AB, SKB (the Swedish Nuclear Fuel and Waste Management Company). It is therefore in practice SKB that has for many years been operating facilities for today's nuclear waste management, see section 1.4. It is also SKB that directly or indirectly conducts the research and development work for the final disposal of the waste.

SKI

Statens kärnkraftinspektion (Swedish Nuclear Power Inspectorate)

SSI

Statens strålskyddsinstitut (National Radiation Protection Institute)

The responsibility of the producer means that the owners of the nuclear power plants are responsible for disposing of the waste in a safe manner

SKB is owned by Vattenfall AB, Barsebäck Kraft AB, OKG Aktiebolag and Forsmarks Kraftgrupp AB

1.2.2 Financing

An important part of the producer responsibility lies in the fact that the costs of the nuclear waste programme are covered by the nuclear power utilities. Monies are collected in special reserve funds in accordance with the rules in the Financing Act. Every year, SKB carries out calculations of the total cost. SKI scrutinizes SKB's cost accounting and the Government then makes a decision on what charge is to be levied on the electricity from nuclear power.

In addition to the approximately SEK 23 billion that was in the reserve funds at the turn of the year 1997/98, more than SEK 11 billion has been used for construction and operation of today's system and for the research and development work. The average charge in 1998 is about one öre (100 öre = 1 Swedish krona; USD 1 » SEK 8.00) per kilowatt-hour. The Financing Act also contains requirements that the power utilities pledge securities for unforeseen costs. The intention is to guarantee that money will be available to take care of the waste even if the NPPs are decommissioned before they have been operated for 25 years or if new, unplanned costs arise /1-3/.

Excerpt from Act on Nuclear Activities

§ 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 Goverment 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).

SKB believes that a deep repository can only be sited where

- The safety requirements are fulfilled, and
- The municipality is positive towards the siting

1.2.3 Rules for licensing

Swedish law specifies how permits and licences for nuclear activities are to be issued. The two most important laws are the Act on Nuclear Activities (Nuclear Activities Act) and the Act on the Management of Natural Resources (Natural Resources Act). The Government can issue permits under these acts after an application has been circulated among the concerned authorities for review and comment.

The Nuclear Activities Act imposes rigorous requirements on safety and radiation protection and is the most important frame of reference for the nuclear waste programme. Review under the Natural Resource Act concerns general questions such as the facility's siting, nature and size. Questions relating to land use, environment and transport are also examined here.

A main rule in the Natural Resources Act is that the municipal council in a concerned municipality must approve an application in order for the Government to issue a siting permit. In other words, the municipality has a veto. The Natural Resources Act also contains the so-called "veto valve" that gives the Government the option of issuing a permit against the will of the municipal council under special circumstances. SKB does not believe that this is an appropriate way to site a nuclear waste facility. The siting work requires the involvement and goodwill of all concerned. It is therefore important that the work be carried out in consensus with the municipality in which the facility is to be located.

An application for a permit under the Nuclear Activities Act and the Natural Resources Act will contain an environmental impact statement, EIS. An EIS, the document resulting from an environmental impact assessment (EIA), must provide an overall assessment of the facility's impact on the environment, human health and conservation of natural resources.

The regulatory framework for licensing will be changed in some respects with the passage of a new environmental code, which lays down tougher requirements on environmental impact assessment and strengthens the influence of authorities and concerned citizens. According to the draft environmental code, the entire application with associated EIS will also be judged by an environmental court with public proceedings.

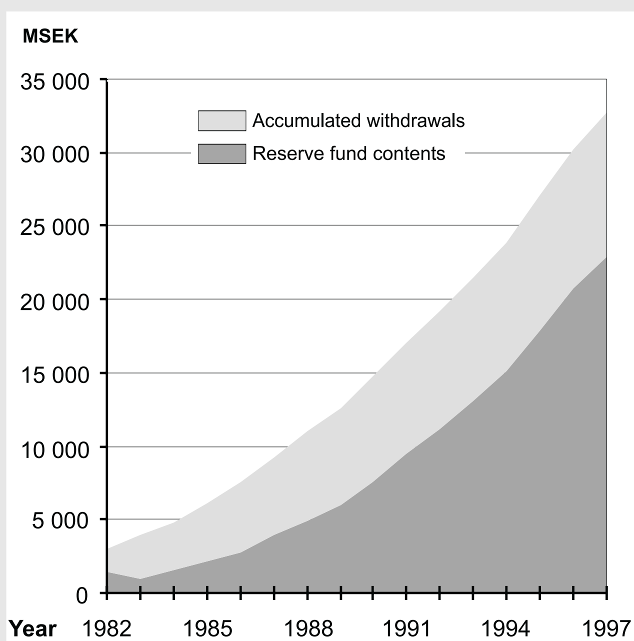
The Nuclear Waste Fund is supposed to cover all costs for management and disposal of the spent fuel, decommissioning and dismantling of the reactors, and conducting the requisite research and development.

The expenses will be spread out over a period of more than 70 years. A large portion of the costs arise in conjunction with decommissioning of the nuclear power plants.

The Nuclear Waste Fund is deposited in an interest-bearing account with the National Debt Office.

The graph shows reserve fund contents and accumulated withdrawals for financing of waste management.

The total costs through 1997 were just over SEK 11 billion. The balance in the funds was about SEK 23 billion at the end of 1997.



1.2.4 Regulations concerning safety and radiation protection

The requirements on safety and radiation protection for both nuclear reactors and waste facilities are set forth in regulations issued by the authorities. The regulations are largely based on internationally established principles for radiation protection.

Requirements on safety and radiation protection are set forth in regulations from the regulatory authorities.

To begin with, these principles require that an activity entailing the handling of radioactive material must be adequately justified (beneficial) in order to exist in the first place. Furthermore, the radiation protection must be as strong as is economically and technically feasible and reasonable. individuals must be guaranteed protection by the use of dose limits. Not just man, but also plants and animals must be protected. This protection must be of equal value for present and future generations and for individuals inside and outside national borders. The radiation protection in management and disposal must be equivalent to that provided in other radiological activities, such as uranium mining, reactor operation or radiological work at hospitals. These general principles can be applied both for the short term to operation of waste facilities and for the long term after closure of a deep repository.

The same fundamental rules should apply to the operation of waste facilities as to the operation of the NPPs. The operation of an NPP is, however, much more complicated than the operation of a waste facility. The radiation protection and safety authorities are in the process of developing special regulations for nuclear waste facilities.

Long-term safety after closure of a deep repository makes new demands on the legislation, owing to the long time spans involved. SSI has issued draft regulations for final disposal of radioactive waste which are currently being circulated for review and comment /1-4/. Similarly, SKI has distributed a memorandum on principles for regulations governing safety in the final disposal of spent nuclear fuel, etc. /1-5/. It mainly concerns how the account of long-term safety should be organized. After having obtained viewpoints from authorities and experts both in Sweden and abroad, SKI and SSI will issue rulings concerning the regulations.

1.3 Previous decisions

In 1976 the state AKA Committee Report /1-6/ was presented, giving Sweden the foundation of a concerted nuclear waste policy. The present-day nuclear waste programme has gradually emerged during the ensuing 22 years. Important decisions on the direction of the work have been based on the results of the studies, safety assessments and programmes presented by SKB, and on the findings of the authorities and the Government regarding them. The wide-ranging discussion in international organizations such as the IAEA and the OECD/NEA have also contributed common principles and conclusions on the nuclear waste question. A brief history of developments in the nuclear waste field is presented in section 2.5.

AKA Committee

A parliamentary committee of inquiry onradioactive nuclear waste.

IAEA

International Atomic Energy Agency

OECD

Organisation for Economic Co-operation and Development

NEA

Nuclear Energy Agency

Some fundamental guidelines that have emerged are the following:

- The Swedish nuclear waste must be disposed of in Sweden. The main line is that the nuclear fuel will be temporarily stored without reprocessing and subsequently disposed of deep down in the bedrock.
- Long-term safety should be based on a method that does not require supervision or maintenance, since this would mean that generation after generation far into the future would have to retain knowledge of the waste and have the will, capability and resources to handle such supervision and maintenance. Knowledge of society in the future is too limited to base long-term safety on this premise.

- There are reasons to retain, as far as is possible, freedom of choice if other, better or simpler solutions should be found or if today's policy of not recy-cling (reprocessing) any of the fuel should be re-evaluated. A review of the alternatives for disposal of the nuclear fuel is provided in a separate report /1-7/.

- The nuclear waste programme should be carried out in stages and be initially oriented towards demonstration deposition (with an option to retrieve) of about ten percent of the estimated total quantity of spent nuclear fuel. A decision to carry out demonstration deposition can be taken when SKB has submitted an application for the facilities that are needed and this application has been reviewed by the regulatory authorities, the concerned municipality and the Government. The application will contain a thorough EIS with, among other things, an overall assessment of the safety and radiation protection aspects and of alternatives as regards both method and site.

1.4 Existing facilities

Today SKB has a final repository for radioactive operational waste, SFR, and an interim storage facility for spent nuclear fuel, CLAB. In addition there is a system for transporting the waste and the spent fuel from the NPPs to SFR and CLAB.

SFR

Final Respository for Radioacative Operational Waste

1.4.1 Final Repository for Radioactive Operational Waste, SFR

There is a final repository for radioactive operational waste, SFR, for disposal of the short-lived low- and intermediate-level waste (LILW) from the NPPs and treatment plants. SFR is situated at the Forsmark Nuclear Power Station and has been in operation since 1988. An expansion is planned for deposition of decommissioning waste from nuclear installations. This will require a new application and a Government decision.

CLAB

Central Interim Storage Facility for Fpent Nuclear Fuel

1.4.2 Central Interim Storage Facility for Spent Nuclear Fuel, CLAB

There is a central interim storage facility for the spent nuclear fuel. It is situated at the Oskarshamn Nuclear Power Station and has been in operation since 1985. The spent fuel is stored in CLAB in water pools in a rock cavern. As of the end of 1997, CLAB contained about 2,700 tonnes of spent fuel, which means that about 55 percent of CLAB's storage capacity is being utilized. CLAB will be full in around 2004, which means that more space is needed to accommodate all fuel from the Swedish NPPs. For this reason, SKB has applied for a permit for the expansion of CLAB with an additional rock cavern with storage pools. An EIS for the expansion has been submitted in support of applications under the Nuclear Activities Act and the Natural Resources Act /1-8/. The Government gave its permission for the expansion of CLAB in August 1988.

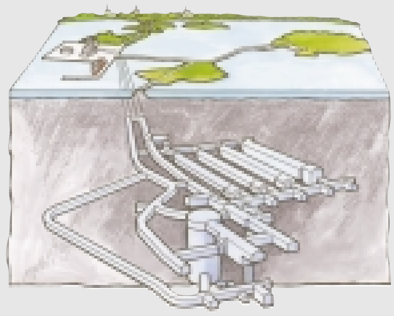
1.4.3 Transportation system

The transportation system consists of transport casks and containers, terminal vehicles and the ship M/S Sigyn

Since all nuclear power plants and waste facilities in Sweden are located on the coast, spent nuclear fuel is transported by sea. The transportation system consists of the ship M/S Sigyn, a number of transport casks and containers, and special vehicles for loading and unloading. The system has been built up and expanded gradually since the start of operation in 1982.

SFR

Start of construction	1983
Start of operation	1988
Capacity	63,000 m^3
In storage	23,000 m^3 (1997/98)
Reception	1,000-2,000 m^3/y
Cost of construction	about SEK 740 million
Cost of operation	about SEK 30 million/y
Operating staff	15 persons
Personnel dose	0.8 mmanSv/y (1997)
Emissions	None

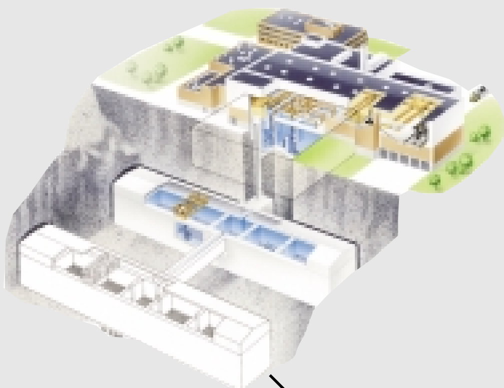


Owner and licenceholder

SKB

Operation and maintenance

Forsmarks Kraftgrupp AB



Planned expansion

CLAB

Start of construction	1980
Start of operation	1985
Capacity	5,000 tonnes of uranium
In storage	2,700 tonnes (1997/98)
Reception	300 tonnes of uranium per year
Cost of construction	about SEK 1,700 million
Cost of operation	about SEK 100 million/y
Operating staff	about 100 persons
Personnel dose	53 mmanSv/y (1997)
Emissions	Negligible

Owner and licenceholder

SKB

Operation and maintenance

OKG Aktiebolag

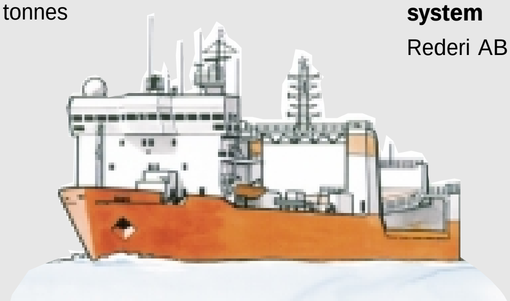
Transportation system

M/S Sigyn

Deadweight tonnage	2,044 tonnes
Length overall	90 m
Breadth	18 m
Draught fully loaded	4 m
Gross tonnage	4,170 tonnes
Engines	2 x 1,170 kW
Cruising speed	12 knots

Terminal vehicle

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



Owner and licenceholder

SKB

Transportation system

Rederi AB Gotland

Transport container for operational waste

Weight	about 58 tonnes
Weight with load	120 tonnes
Length	about 7 m
Width	about 4 m
Height	4 m
Wall thickness	7-20 cm
Material	Steel
Capacity	12-16 moulds or 3 concrete tanks

Transport cask for spent nuclear fuel

Weight with load	about 80 tonnes
Length	about 6 m
Diameter	about 2 m
Wall thickness	32 cm
Material	Steel
Capacity	17 fuel assemblies from BWRs or 7 fuel assemblies from PWRs

Transport cask for core components

Weight	about 70 tonnes
Length	about 6 m
Diameter	about 2 m
Wall thickness	33 cm
Material	Steel
Capacity	5 tonnes

1.5 Knowledge base

An important prerequisite for the implementation of the Swedish nuclear waste programme is the base of knowledge that is required to proceed with the remaining steps in the waste programme, i.e. the encapsulation plant and the deep repository. More than two decades of research, technological development and public debate have gone into the accumulation of this knowledge base.

An important component is the results of the research concerning what long-term changes might influence the safety of the repository. The research has been conducted at universities and institutes of technology with SKB's support, as well as under SKB's own auspices. The Äspö Hard Rock Laboratory (HRL) and the former research station at the Stripa Mine in Bergslagen have comprised key resources. Many countries are studying similar solutions to Sweden's, and the international exchange of information is therefore important.

In parallel with this basic research, methods have been developed for compiling the research findings and other information in assessments of the long-term safety of the repository. A number of safety assessments have been carried out for the planned deep repository.

Implementing the waste programme also requires new or refined technology in various fields. This applies above all to technology for encapsulation and deposition of the waste, but to some extent also construction and operation of the deep repository. Such development has been going on for a long time. A project is under way today at the Äspö HRL to test the deep disposal technology under realistic conditions. The encapsulation technology will be further developed during the coming years, especially at the Canister Laboratory which SKB has built in Oskarshamn.

1.6 What remains to be done?

With SFR, CLAB and the transportation system, SKB is able today to manage the radioactive waste from nuclear power in a safe manner. The main line for the ultimate disposal of the spent nuclear fuel, i.e. deep geological disposal of encapsulated fuel, requires in addition an encapsulation plant and a deep repository.

There remain to be built

- an encapsulation plant
- a deep repository

Much of the knowledge required to build these facilities and analyze the long-term safety of the deep repository is available today. Demonstration of the proposed technology for encapsulation and deep disposal has therefore assumed greater weight in SKB's research and development programme in recent years. The safety-related and technical aspects of the siting of a deep repository are also important elements in today's research and development work.

The next three chapters provide a more detailed description of the background and premises. They deal with (in the order given) different possible disposal methods and the choice of main alternative made in Sweden, the envisioned design and function of the chosen system, and how long-term safety will be guaranteed in the deep repository. Chapters 5–10 present the programme for research, development and technology demonstration, with an emphasis on the coming three years.

2 Method selection

Choosing a method for disposing of spent nuclear fuel is not just a technical question. It is also a question of ethical judgements, political decisions and not least decisions as to what should be done now and what can be postponed until the future.

The main strategy in Sweden is that spent nuclear fuel, after a period of supervised storage, should be deposited deep down in the bedrock. This strategy has been established in several Government decisions and is the one being followed by SKB in its work. It entails that the present-day generation, who have benefited from the nuclear power electricity, should assume concrete responsibility for waste disposal.

Freedom must be allowed to change development direction during the time we are planning and carrying out deposition, or even after-wards. Science and technology are constantly advancing, and treatment methods may for example be developed to reduce the radiotoxicity of the waste in the long term. Even if there is no method in sight that renders geological disposal superfluous as a long-term solution, there is every reason to keep track of new developments.

2.1 Three principles for management of hazardous waste

There are three different principles for managing hazardous waste in general: dispersal and dilution, conversion into less hazardous substances, and isolation.

Three principles
- dispersal and dilution
- conversion into less hazardous substances
- isolation

Dispersal and dilution

The first principle, dispersal and dilution, was long applied when industrial and household wastes were discharged into air and water. As insight into the consequences of these practices for man and the environment has grown, this line has often been modified or abandoned, either by treating the effluents or emissions or by modifying the polluting processes. Dispersal and dilution are, however, still practised. One example is emissions from the combustion of fossil fuels: The waste products, carbon dioxide and impurities such as sulphur and nitrogen compounds, are released and dispersed in the atmosphere.

This principle cannot be used for radioactive waste other than for very small quantities. The principle is not aesthetically pleasing, and it violates various international conventions on nuclear waste management.

Conversion into less hazardous substances

The second principle, converting hazardous waste into less hazardous substances and then disposing of these, is exemplified by the use of catalytic converters in automobiles: Hazardous waste products in the vehicle exhaust gases are converted to less hazardous ones and then released into the atmosphere or disposed of when the catalyst becomes waste.

Transmutation entails that long-lived radionuclides are converted to short-lived or stable nuclides by bombardment with neutrons

For radioactive waste there is no method available today for rendering the waste less hazardous. In the long term there is the possibility that transmutation (see sections 2.2.5 and 9.4) could contribute to waste management by reducing the quantities of long-lived radionuclides in spent nuclear fuel. Even if a breakthrough is made in this method in the future and it gains acceptance, the radioactive waste remaining after transmutation must be disposed of.

Isolation

The deep repository is based on the principle of isolating the waste

The third principle, isolation, is based on keeping the hazardous waste separated from man and the environment. One example is the final repository for mercury that is being discussed in Sweden today /2-1/. The idea here is to isolate the waste almost completely. The long-term discharges should be so small that the effects are negligible.

Isolation in different forms is the main principle that is being discussed for radioactive waste all over the world. The principle is particularly applicable to such waste, since the volumes are relatively small. Furthermore, the toxicity of the waste declines as the radioactive materials decay. This means that a specific time perspective can be adopted, which is not the case for e.g. heavy metals, whose toxicity doesn't change. The safety of the Swedish KBS-3 system for deep disposal of spent nuclear fuel is based on isolation.

2.2 Different modules in waste management

A complete programme for management of radioactive waste is made up of a number of elements or modules. These can be combined in different ways into programmes and be given varying technical designs. The purpose of most modules is to isolate the waste from man and the environment in one way or another.

In the short term the waste can be kept in supervised storage. This is done to allow the radioactivity to decay so that further handling is simplified (interim storage) and/or as a temporary solution pending decisions on coming steps (supervised storage).

In the long term there are really only two realistic fundamental solutions: emplacing the waste in media that are stable over a very long period of time, for example deep in the crystalline bedrock, or getting rid of the waste once and for all, for example by launching it into outer space. The first solution is called geological disposal since all media that are stable over a long time are geologic. The second solution could be referred to as ultimate removal.

There is also the option of altering the content of the waste. Spent fuel contains uranium and plutonium, which can be re-used in new fuel. By separating and re-using these elements, the fuel raw material is better utilized, at the same time as the long-range toxicity of the fuel is reduced because plutonium is consumed as fuel. This separation process in the context of nuclear fuel is called reprocessing. The method requires large and complex plants. The situation becomes even more complicated when we consider the possibility that new technology in the future may make it possible to utilize/consume more elements. One such potential technology where a great deal of development remains to be done is transmutation. The purpose of transmutation is to convert long-lived substances into short-lived ones, at the same time as more energy is recovered.

Four strategies

- Supervised storage
- Geological disposal
- Ultimate removal
- Reprocessing/ transmutation

Thus, both reprocessing and transmutation alter the contents and properties of the fuel and can therefore be regarded as possible steps in waste management. Regardless of how far reprocessing, recycling and transmutation are driven, in the end there is a certain quantity of waste that must be dealt with, both in the short and long term.

In summary, four main modules or methods can be used to compose a complete programme of waste management: Supervised storage (interim storage), geological disposal, ultimate removal and reprocessing with possible transmutation. Figure 2-1 shows the different methods and how they are related to each other.

2.2.1 Supervised storage - interim storage

An initial period of supervised storage will, for technical reasons, always be included in the management of spent fuel. The radioactivity and heat flux of the spent fuel decrease during this period, facilitating further handling.

In Sweden and many other countries, this storage takes place under water in pools (in CLAB), see Figure 2-2. The water acts as a radiation shield while at the same time cooling the fuel. SKB plans to keep the fuel in interim storage for about 30 years, but the plant can continue to be kept in operation with cooling and purification of the pool water and with ventilation. Based on Swedish and international experience, it is believed that CLAB could, with the right operation and maintenance, be kept operating for a hundred years or more /2-2/.

CLAB

Central Interim Storage Facility for Spent Nuclear Fuel

Wet storage

Water both shields off the radiation and cools the fuel

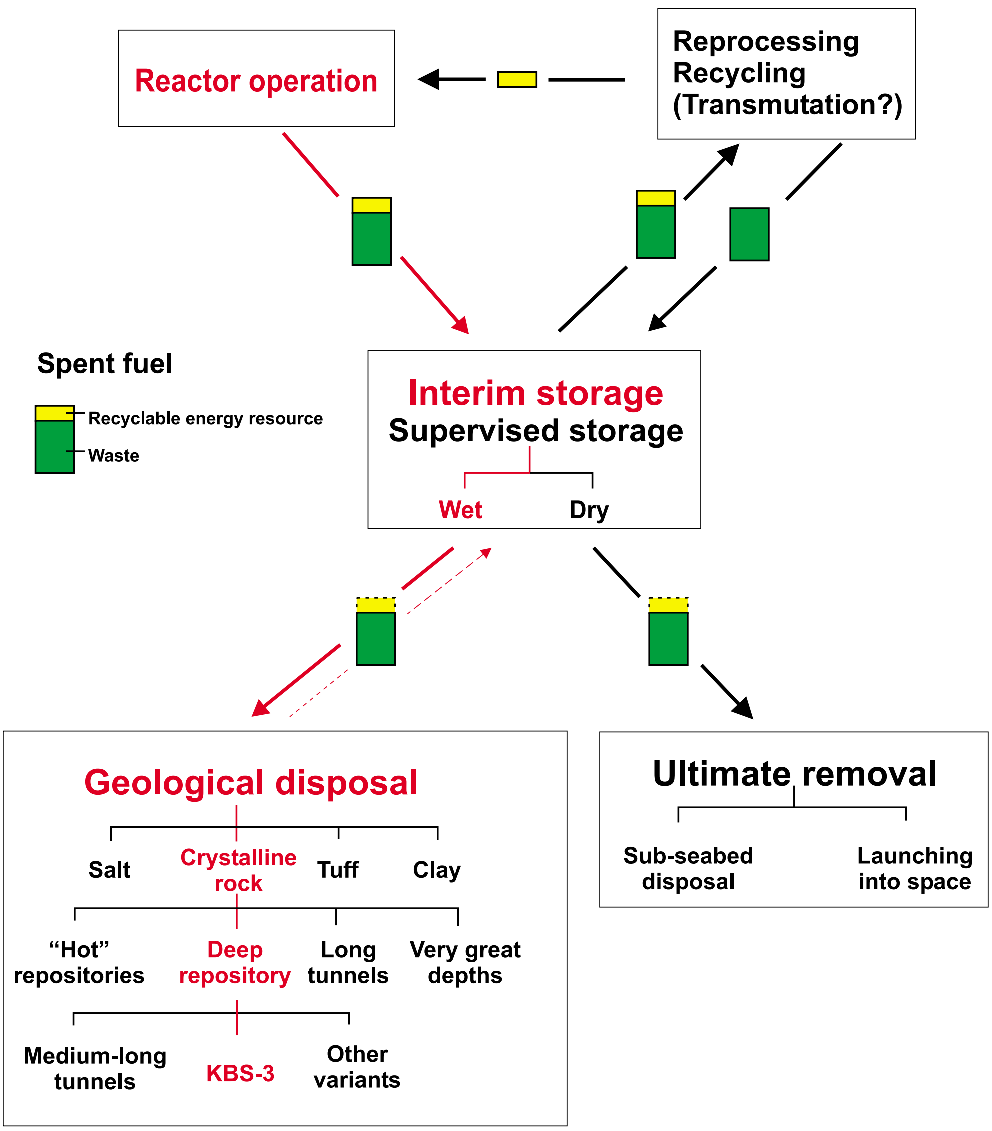


Figure 2-1. *Different modules in the management of spent nuclear fuel. The modules and alternatives included in the Swedish system are marked with red.*

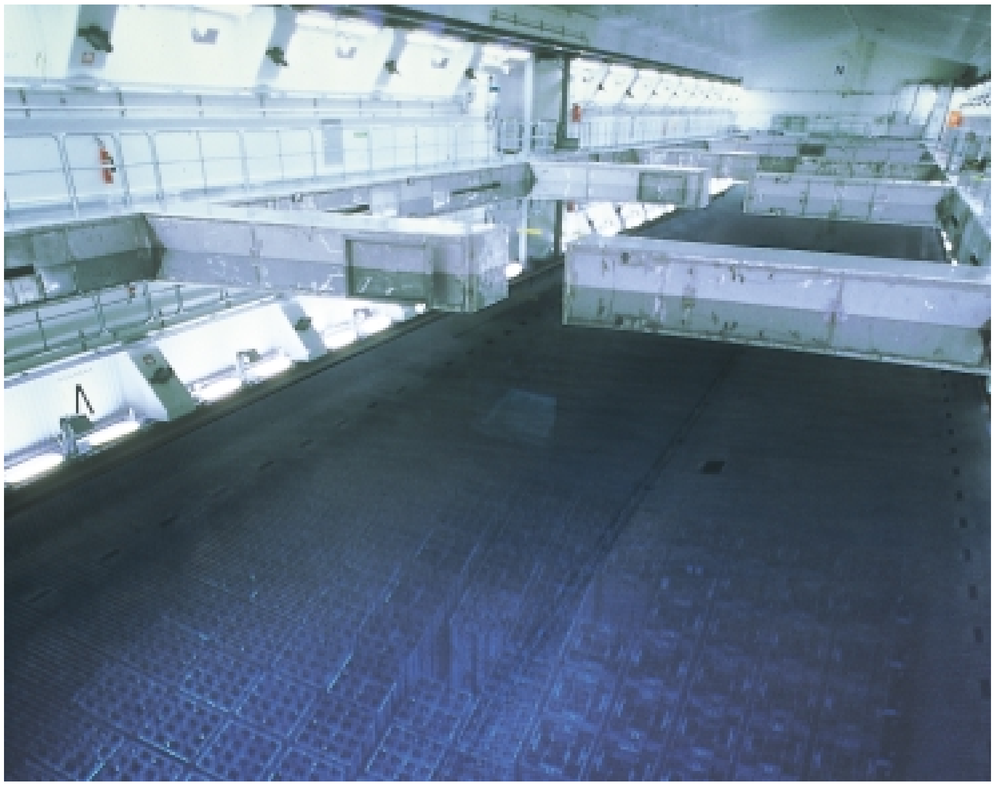


Figure 2-2. *Wet interim storage of spent nuclear fuel in CLAB outside Oskarshamn.*

Dry storage

The radiation is shielded off by concrete or steel. The fuel is cooled by air

Another method of interim storage is dry storage, where the fuel can be cooled by air circulation. The fuel is stored either in casks similar to those used for fuel transport (Figure 2-3) or in radiation-shielded rooms in a storage building. High-level waste (HLW) from reprocessing is transformed into solid glass. Casks of glassified (vitrified) fuel are stored dry in storage buildings. Dry storage requires less maintenance than wet storage. The method is used in Canada, Germany and the USA.

Both dry and wet storage have been approved by the authorities from the view-point of radiation protection and safety. Different countries have chosen the storage method that fits in best with the rest of the national system. Storage entails very small safety risks as long as supervision is effective. If control and supervision should for some reason fail, this increases the risk of events that can have serious consequences, for example due to loss of cooling or diversion of nuclear material /2-3/.

Supervised storage is not a long-term solution

Supervised storage can in principle continue indefinitely with suitable maintenance. Since guarding of the storage facility is not a feasible option over thous-ands of years, however, some form of long-term solution is needed to replace supervised storage. Supervised storage should therefore be regarded primarily as a means of keeping the fuel under direct control pending a final decision on disposal method. The Nuclear Activities Act explicitly requires final disposal, see fact box on page 29.

2.2.2 Geological disposal

Geological disposal entails that the waste, following a period of interim storage, is emplaced at great depth in a geological medium that is stable over a very long time. Geological disposal can be used for both spent nuclear fuel that is not reprocessed and for high-level, long-lived waste from reprocessing. The former alternative is known as direct disposal.

Different media

The geological media that are being considered for hosting a deep repository vary according to the geological conditions existing in various countries. Rock salt formations are being studied in Germany; crystalline rock in Finland, Canada and Sweden; clay in Belgium; and tuff (a volcanic rock) in the USA. Both crystalline and sedimentary bedrock are being studied in France. All of these formations are very old – tens of millions of years or more – and change very slowly. The bedrock being considered in Sweden is between one and two billion years old.

Different repository designs

The repository can be designed in different ways in each of the media. Several different alternative principles can be considered in the bedrock we have in Sweden:

- The waste is deposited in a system of short tunnels at a depth of 400–700 metres in water-saturated rock (e.g. KBS-3).
- The waste is deposited as above, but the repository is arranged as a few parallel tunnels many kilometres in length.
- The waste is placed in a dense, cage-like array in the rock (WP-Cave).
- The waste is deposited in very deep boreholes (several kilometres in depth).

There are variants of each of these basic principles, in terms of how the repository is arranged geometrically as well as how the waste is encapsulated. The design in the Swedish programme has been gradually developed towards what is now the main strategy, a deep repository of the KBS-3 type. Different alternatives have been considered and rejected because they do not offer greater safety or because safety is more difficult to assess.

Bentonite

Clay of volcanic origin with suitable swelling properties

Figure 2-3. *Dry interim storage of spent nuclear fuel in Gorleben, Germany.*

The KBS-3 design of a deep repository for spent nuclear fuel consists of a system of horizontal tunnels spaced at a distance of 30–40 metres. The fuel is placed in tightly sealed copper canisters with a high-strength cast iron insert. The canisters are surrounded by bentonite clay in deposition holes bored in the floors of the tunnels. Variants with e.g. horizontal deposition holes are also conceivable.

Chapter 4 describes how long-term safety has been built up with multiple barriers: canister, bentonite clay and rock. A deep repository will be kept open as long as deposition of waste continues, i.e. for several decades, after which it will be supervised. Supervision can be extended over a longer period if desired. The long-term safety of the repository is, however, not dependent on inspection or maintenance.

2.2.3 Ultimate removal

Ultimate removal
is not a realistic alternative

Different methods have been discussed for rendering the waste virtually inaccessible (ultimate removal). One possibility would be to launch the waste into space with a rocket, but this has been rejected due to the risks involved with rocket launches.

Other variants are emplacement in deep-sea sediments or under the Antarctic ice sheet. Great international interest has particularly been devoted to sub-seabed disposal. The waste is encapsulated and sinks under its own weight about 50 metres down into the thick bottom sediments at a depth of about 4,000 metres in the Atlantic Ocean. The sediments protect the canister and retain any escaping radioactive substances. Seabed disposal can also be done by stacking the waste canisters in deep boreholes under the seabed. The method has some safety-related advantages but is not being studied further for political reasons.

Thus, no form of ultimate removal is being discussed seriously today as a module in the management of spent nuclear fuel and similar waste. The borderline between geological disposal and ultimate removal is not clear-cut. Emplacement in deep-sea sediments has been regarded here as ultimate removal, but could also be counted as a geological disposal method.

2.2.4 Reprocessing and recycling

Transuranic elements
Elements that are heavier than uranium

At today's reprocessing plants, the nuclear fuel is first chopped up into small pieces and then dissolved in a strong acid. By means of chemical treatment in several stages, uranium and plutonium are separated from fission products and other transuranic elements. Uranium and plutonium can, after purification and chemical processing, be re-used as fuel raw material. Plutonium is included in MOX fuel (Mixed OXide fuel), which consists of a mixture of uranium oxide and plutonium oxide.

Fission products
Nuclides formed by nuclear fission

In reprocessing, uranium and plutonium are separated from the waste products

The waste, i.e. fission products and other transuranic elements, is mixed into molten glass and poured into containers. The vitrified waste emits radiation and heat and must, just like the spent nuclear fuel, be stored for awhile before it can be deposited in a deep repository. Reprocessing also gives rise to other long-lived waste that must be disposed of in a similar manner.

Reprocessing takes place in large plants where handling of the nuclear material is remote-controlled and radiation-shielded. Reprocessing plants exist today in France (La Hague), see Figure 2-4, the UK (Sellafield) and Russia. A plant is also being built in Japan. The aggregate annual capacity of today's reprocessing plants is approximately 2,800 tonnes, while the quantity of spent fuel arising in the world every year is about 10,000 tonnes.

Figure 2-4. *Reprocessing plant in La Hague, France.*

The need for natural uranium for fuel can be reduced by 20–30 percent by re-use of uranium and plutonium. Similarly, the need for enrichment can be reduced by about 25 percent. The cost of recycling is high, however. At today's uranium prices it is much cheaper to use new uranium. The time from when spent fuel is discharged from the reactor until it can be converted to new MOX fuel is just under ten years.

Enrichment

Process for increasing the fraction of fissionable uranium so that it can be used as fuel in lightwater reactors

Re-use of MOX fuel in light-water reactors can be done in two or three cycles. After that plutonium has an unsuitable isotope composition which degrades the safety characteristics of the reactor. Plutonium can, however, be burned/consumed more efficiently in fast reactors, see Chapter 9. Fabrication of MOX fuel imposes much tougher demands on radiation protection than fabrication of ordinary nuclear fuel.

The uranium and plutonium separated in reprocessing are re-used in MOX fuel

MOX fuel is used in France, Switzerland and Germany, among other countries. Capacity for fabrication of MOX fuel is slightly lower today than the quantity of plutonium that is separated in reprocessing.

The waste management system in the case of reprocessing consists of the following steps:

- Interim storage
- Reprocessing
- Re-use of uranium and plutonium in fuel fabrication.
- Vitrification (glassification) of the high-level waste solution, which contains fission products and other transuranic elements, and treatment of other waste.

The high-level vitrified waste and other long-lived waste from reprocessing must be disposed of in a manner similar to spent fuel.

2.2.5 Transmutation

Transmutation entails converting (transmuting) long-lived radionuclides to more short-lived ones with the aid of nuclear reactions. To bring this about, the long-lived radionuclides are subjected to intense neutron bombardment. The process also generates energy that can be used to produce electricity, for example.

Making transmutation a feasible option requires development of

- partitioning technology
- accelerator technology

A prerequisite for efficient transmutation is that the different substances in spent fuel can be separated (partitioned). This requires development of reprocessing technology. Nuclides that need to be separated to reduce the long-range radiotoxicity of the fuel are mainly plutonium, but also neptunium, americium and other transuranic elements, as well as technetium-99 and iodine-129. Development of partitioning technology has been going on for several decades, but a great deal of research remains to be done before the complete technology is available on an industrial scale and is sufficiently efficient. A goal in this development that has been mentioned in international contexts is to reduce the quantity of long-lived radionuclides to one-hundredth.

The neutron fluxes that are needed can be obtained in so-called "fast reactors" or in a large accelerator. The accelerator would be connected to a new type of nuclear reactor under development where the nuclides to be transmuted are bombarded with neutrons.

The transmutation sequence consists of the following steps:

- Separation of the substances to be transmuted from the high-level waste solution from reprocessing.
- Vitrification of remaining waste solution, which contains the short-lived fission products.
- Fabrication of transmutation fuel with the separated long-lived substances.
- Irradiation of the fuel in a fast reactor or an accelerator-driven system.

After transmutation, waste remains that must be emplaced in a deep repository

The operating properties of the transmutation fuel deteriorate after some time in the reactor. It must then undergo chemical partitioning once again, i.e. the above steps are repeated in several cycles. The high-level vitrified waste and other long-lived waste from the processes must be dealt with in a manner similar to spent fuel. As in traditional reprocessing, doses to personnel and releases of radioactive substances are obtained in every step. It is difficult to judge how great these will be at the present time.

Transmutation technology is still in the research stage. Several decades of work is required before it can be exploited on an industrial scale. SKB is supporting the research on transmutation.

Transmutation technology will require several decades of development before it can be industrially available. This development requires funding which only large countries or unions can provide. SKB's work and plans within the transmutation field are described more thoroughly in Chapter 9.

2.3 Selecting a main alternative

The selection of a method for managing and disposing of spent nuclear fuel includes both major decisions on fundamental principles and detailed choices between different technical solutions. In Sweden, settling on a main alternative has been a long process where general aspects and technical details have been discussed in parallel. The process has been going on for several decades, during which time it has been affected by new findings which are constantly coming to light.

2.3.1 Two main questions

In selecting a method for disposing of spent fuel, it has first been necessary to find an answer to two main questions (since ultimate removal is not a realistic alternative):

1. Should the spent fuel be reprocessed or not?
2. Should the long-term solution be to wait and see, or to deposit in geological formations?

Reprocessing affects the form of and to some extent the contents of the waste, but this does not have any crucial importance for how the waste needs to be dealt with in the long term.

If the choice is made to wait with a long-term solution, there is really only one option: supervised storage for an indefinite period of time, whether the spent fuel is reprocessed or not.

If geological disposal is chosen, a number of choices of a more technical nature remain. A decision must be made on geological medium (e.g. rock, salt, clay) and the general principle for and detailed design of the repository.

2.3.2 Aspects of the problem

Time aspects

Time aspects enter into the design of a waste management programme in different ways. One crucial question is whether today's generation is to solve the waste problem or whether responsibility is to be shifted in all or in part to future generations. This question ties in with the pace of technical development: Which technologies and methods will be available in the future? How can a programme that is devised today be flexible enough to adapt to new developments? If geological disposal is chosen, for example, will it be possible to retrieve the waste from the repository after it has been deposited?

Energy supply

The design of a waste programme is in some respects linked to the question of the future national energy supply. An investment in reprocessing and recycling is not realistic without the prospect of continued use of nuclear power in the future. This is also true of transmutation, which in itself requires reprocessing but also a large investment in new nuclear power technology.

Nuclear weapons proliferation

Questions relating to nuclear weapons proliferation also enter the picture. Reprocessing, for example, is a technology that can be used to produce fissionable material for nuclear weapons manufacture. On the other hand, the recycling that follows on reprocessing leads to the burning of more fissionable material in nuclear reactors under controlled conditions than does direct disposal in deep repositories.

2.3.3 Four possible strategies

If ultimate removal is included, four possible programmes or strategies can be formulated for management of long-lived HLW:

SKB's main alternative is based on supervised storage in CLAB followed by direct disposal in a deep repository

- **Supervised storage**
  The spent fuel is stored indefinitely under controlled conditions, and the choice of disposal option according to one of the following alternatives is postponed.
- **Direct disposal in deep repository**
  After interim storage, the spent fuel is encapsulated and deposited in a deep repository, without the need for supervision or maintenance but with the option of retrieval.
- **Reprocessing (transmutation?) and disposal in deep repository**
  Uranium and plutonium (and possibly other long-lived nuclides) are separated by chemical means to be re-used as nuclear fuel. Residual waste is emplaced in

a deep repository. In a possible future variant, transmutation can also be included in this strategy.

- **Ultimate removal**
  The spent fuel is rendered inaccessible for all future time, for example by launching into space.

The different strategies are more or less realistic and all have their advantages and disadvantages. The most important ones are summarized in Table 2-1.

Table 2-1. Advantages and disadvantages of different strategies for management of spent nuclear fuel

Strategy	Advantages	Disadvantages
Supervised storage	Good control can be maintained over the material and safety Preserved flexibility for all types of future management or treatment	Places responsibility for safety on future generations Safety requires active control, inspection and maintenance Fissionable material remains and must be monitored Sensitive to disruptions in society such as war, terror, strikes, economic recession, etc. Not a long-term solution
Direct disposal in deep repository	Few handling steps means low dose load to personnel Technology available now and relatively simple Poorly soluble waste product - especially the very long-lived nuclides Retrievable and reparable far into the future Little potential for serious consequences	All long-lived nuclides remain in the waste Poor utilization of uranium, which still has most of its inherent energy left The very long time perspective Fissionable material remains far into the future
Reprocessing and disposal in deep repository	Energy in uranium is utilized better in light-water reactors and much better in breeder reactors Reduces the need for uranium enrichment Reduces the amount of uranium and plutonium in the waste Well-determined and controllable form for the high-level waste Toxicity in the long term (<1,000 years) is lower than for direct disposal	Many handling steps give increased dose to personnel and risk of increased releases High costs More waste types and perhaps greater volume of waste to be disposed of Increased risk of proliferation of nuclear weapons material
Reprocessing, transmutation and disposal in deep repository	Energy in uranium can be utilized much better in breeder reactors and in accelerator-driven systems The quantity of long-lived radionuclides in the waste decreases considerably The long time perspective is reduced for the deep repository	Many handling steps give increased dose to personnel and increased risk of releases Further increased cost More waste types and perhaps greater volume of waste to be disposed of Increased risk of spreading of technology that can be used for production of nuclear weapons material Technology not available today - uncertain if and when
Ultimate removal	Waste eliminated, cannot cause harm Deep repository not needed	Technology not available today Risk of failures that cannot be repaired

2.4 The Swedish main alternative

How, then, has the Swedish programme been designed, what choices have been made and what evaluations lie behind the choices? The main alternative has gradually taken on more detailed form over the past 20 years or so. Following is an account of the most important decisions.

To reprocess or not to reprocess?

Sweden has chosen not to reprocess the spent fuel. This was decided in the 1980s after the KBS-3 report had been approved (see section 2.5). Behind the decision lies the desire not to contribute to the risk of nuclear weapons proliferation. Furthermore, reprocessing is a costly method.

Sweden does not reprocess spent nuclear fuel

Choice of long-range solution

The intention in Sweden is to implement geological disposal. Prior to disposal, the fuel will be stored for about 30 years (interim storage). Behind this choice lies the evaluation that it is today's generation that should dispose of the waste, since it is today's generation that has benefited from the nuclear power; furthermore, there is an uncertainty regarding the future development of society that cautions against waiting.

The longterm solution is geological disposal of the spent fuel

Choice of geological medium

In Sweden, disposal is planned to take place in crystalline bedrock. This is the most common type of bedrock in the country and is suitable from a technical-scientific point of view. Many countries besides Sweden have chosen disposal in crystalline bedrock as their main alternative.

The Finnish government has decided to use geological disposal. Site selection will be made in 2000. Finland plans to use the same method as Sweden.

Choice of repository design principle

As was noted in section 2.2.2, the repository can be designed according to several different principles. The KBS-3 design with a system of short tunnels at a depth of 400–700 metres is the design that has been chosen in Sweden. Other alternatives have been compared with the KBS-3 concept in terms of feasibility, short- and long-term safety and costs /2-4/. The outcome of the comparisons has been to the advantage of the KBS-3 concept, and the strategy in Sweden has therefore been to continue development of this alternative.

SKB's strategy is to design the repository according to KBS-3

Choice of detailed design

Assuming that disposal can be done in a KBS-3-like repository, the repository can be designed in different ways. To achieve optimum performance, different combinations of tunnels and holes are being studied where the canisters can be deposited standing or lying, in a row in the same hole/tunnel or with separate positions for each canister, etc.

The principle for KBS-3 is a system of parallel tunnels where holes for emplacement of canisters are bored in the floors of the tunnels. An alternative would be to place the canisters directly in medium-long tunnels radiating in a herringbone pattern from a central tunnel. This and similar versions can be quite feasible to execute with undiminished safety, but the design with deposition tunnels with separate holes for the canisters has been given top priority since it has been judged to be easier to build such a repository. However, SKB continues to evaluate alternative disposal methods, see section 7.4.2.

The canister can be designed either to isolate the waste while it is being handled, or also to keep the radioactive materials separate from man and the environment for a long time. The choice of canister material and design is thus dependent on what requirements are made on the canister, as well as on the medium in which it is planned to be emplaced. Different canister designs have been studied and evaluated. In Sweden the strategy is to use a canister made of copper and iron (copper for corrosion resistance and iron for mechanical strength) to serve as an effective component in a multiple barrier system.

Retrievability

The deep repository is designed so that it is always possible to retrieve deposited waste

A choice of another character is the degree of retrievability of the waste after disposal. Future technological advances or scientific discoveries may make it desirable to gain access to materials in the fuel. Another possibility is that future generations for one reason or another wish to modify, supplement or improve the design or performance of the repository and therefore access the waste.

As the main alternative is designed, it is possible to retrieve the fuel at all stages, although it becomes more involved and costly the further along in the process it is done. Retrieval is possible because deposition is carried out under controlled forms in a rock with high mechanical stability /2-5, 2-6/. However, retrievability requires that information on the content and design of the repository be preserved for people in the future /2-7/.

2.5 Historical background

The Swedish programme for radioactive waste management has been developed over a period of more than 25 years. A brief recounting follows below.

2.5.1 Overview

The development of the programme for radioactive waste management can be viewed in three phases:

1. **1977-84. Programme establishment and pioneer work**
   The foundations of the Swedish disposal system were laid during this period. SKB gathered important data on the Swedish bedrock and published safety assessments. An important milestone and conclusion of the period was the KBS-3 study which was approved by the Government in 1984, after thorough scrutiny, as a basis for allowing the fuelling of new reactors. The work during this period was focused almost entirely on technology and safety.

2. **1984-92. Consolidation and broadening**
   Knowledge concerning possible ways of disposing of nuclear fuel in Swedish bedrock was deepened and broadened during this period. The Äspö HRL was built. Alternative methods were presented and evaluated. KASAM raised issues such as ethics and decision theory. In FUD-Programme 92, SKB concluded that the time was ripe to begin a concrete project to site and build an encapsulation plant and a deep repository in an initial stage. This strategy received the approval of the authorities and the Government.

3. **1992-. Data collection and decision making**
   This phase is currently in progress. The research is continuing and technology development has been intensified. The nuclear waste question is now being put before the municipalities and the public. Local and regional involvement is also leading to questions such as Why here? and What are the benefits? Work on environmental impact assessments is being initiated in consultation with municipalities, county administrative boards, and the safety and radiation protection authorities. The Government is gradually refining its requirements on background data and the decision-making process.

SKB has on five occasions, at intervals of three years, submitted an account of its programme for research and development to the authorities and the Government. The programmes have been circulated for review and comment, and the Government has then approved the accounts. In some cases the Government has required a supplementary account or explained its view of the focus of the work.

2.5.2 Chronological summary of important inquiries

Little attention was given to the nuclear waste issue up to the mid-1970s, outside of a small circle of experts. Thereafter, once it had attracted attention in the public forum, large inquiries were carried out. Some of the most important inquiries are presented below in chronological order, with a special emphasis on strategy and method selection.

AKA Committee inquiry - 1976

In 1972, the Minister of Industry issued terms of reference to a parliamentary committee on high-level waste from nuclear power plants. The committee's main report came in the spring of 1976 and recommended reprocessing of the nuclear fuel and final disposal of encapsulated vitrified high-level waste in the Swedish bedrock /2-8/. The committee also mentioned the possibility of direct disposal of the nuclear fuel, even though the technology was not considered sufficiently developed at that time. A concrete proposal that was subsequently implemented was that a central interim storage facility for the spent fuel should be built.

AKA Committee

A parliamentary committee that conducted an inquiry on radioactive waste management

The statements of comment were critical towards Swedish reprocessing, but recommended direct disposal and emphasized the need for research in the field. Otherwise the statements of comment were overwhelmingly positive towards the findings and proposals of the committee.

With the benefit of twenty years' perspective, we can now conclude that the committee's report and its circulation for review and comment laid the foundation for the subsequent course of events in the nuclear waste field, and that it has greatly influenced SKB's work. The AKA Committee report has stood the test of time in terms of the fundamental principles it lays down for the disposal of high-level waste and the design of the disposal system.

KBS-1 inquiry - 1977

In 1976, Sweden got a new Government and Riksdag that passed the "Stipulation Act". The Stipulation Act required that the nuclear power utilities should produce an agreement which adequately satisfied the need for reprocessing of spent nuclear fuel and demonstrate how and where an "absolutely safe final disposal" could take place. Alternatively, they could demonstrate how and where an absolutely safe final disposal of spent, unreprocessed nuclear fuel could take place. To meet these requirements, the four nuclear power utilities Statens Vattenfallsverk, Sydkraft AB, Oskarshamnsverkets Kraftgrupp AB and Forsmarks Kraftgrupp AB started the KBS project at the end of 1976.

The KBS project first carried out a study of disposal of vitrified high-level waste from reprocessing /2-9/. The report and the reprocessing contracts with French COGEMA were submitted in support of applications to the Government for permits to fuel the Ringhals 3 and Forsmark 1 reactors.

COGEMA

French state-owned company that sells reprocessing services via La Hague, see Figure 2-4.

The many reviewing bodies pronounced generally positive judgements on the KBS proposal. The Government found in its decision of 5 October 1978 that further test drillings and measurements were needed to demonstrate that sufficiently large rock formations exist in Sweden with the properties required in the safety assessment.

KBS conducted broader studies. Renewed applications were made in February 1979. In its statement of comment on the supplement, SKI said in March 1979: "In the overall assessment of safety, the supplementary study has not given the Inspectorate reason to change its previous judgement, as presented in the statement of comment of 9 May 1978, that the KBS-project's proposal for the management of spent nuclear fuel and final disposal of high-level waste satisfies the requirements made by the Stipulation Act. In the opinion of the Inspectorate, the available material thus points towards acceptable possibilities for disposal in Swedish rock of the waste from at least the two reactors currently under consideration".

KBS-2 inquiry - 1978

The KBS project also studied the alternative without reprocessing, i.e. direct disposal of spent nuclear fuel. This work resulted in the so-called KBS-2 Report /2-10/, which was in general received positively by both Swedish and foreign reviewing bodies. The conclusion of the National Research Council within the National Academy of Sciences in the USA was that available technical data are sufficient to support the conclusion in KBS-2, that radionuclides will not be released at an unacceptable rate from a repository built according to the specifications in KBS-2, providing that its construction conforms to good engineering principles and that the site has been well chosen.

KBS-3 inquiry - 1983

Work on further development of the methods for direct disposal continued. When the Forsmark 3 and Oskarshamn 3 nuclear reactors were ready to be commissioned, the power utilities submitted an application based on a deeper body of material regarding direct disposal of spent nuclear fuel – KBS-3 /2-11/. No particular site was designated here as being suitable for a final repository. Instead, a number of investigated study areas were presented: Finnsjön, Fjällveden, Gideå and Kamlunge. Like the preceding KBS reports, KBS-3 was subjected to thorough review and scrutiny.

The Government found that "the method in its entirety has been found essentially acceptable with regard to safety and radiation protection" and approved the fuelling permit application for the two reactors in June 1984. All nuclear reactors in the Swedish nuclear power programme had thereby obtained operating licences.

R&D-Programme 84 - 1984

The detailed repository design and site selection required more research and development. As an appendix to the applications for fuelling permits for the last reactors, SKB also submitted a research programme that related mainly to the KBS-3 method. SKI, SSI and SKN commented on the programme and accepted it, with some minor criticisms.

SKN

Statens kärnbränslenämnd (National Board for Spent Nuclear Fuel)

SKN is now defunct, and its functions have been transferred to SKI, KASAM and the Nuclear Waste Fund

R&D-Programme 86 - 1986

In 1986, SKB submitted the first complete research programme pursuant to the new Act on Nuclear Activities /2-12/. The guidelines which the research in SKB has followed since KBS-3 were summarized and elaborated on in R&D-Programme 86 in the following ways:

- The radioactive waste products shall be disposed of in Sweden.
- The spent nuclear fuel shall be temporarily stored and finally disposed of without reprocessing.

- Technical systems and facilities shall fulfil high standards of safety and radiation protection and satisfy the requirements of the Swedish authorities.
- The systems for waste management shall be designed so that requirements on the control of fissionable material (safeguards) can be fulfilled.
- In all essential respects, the waste problem shall be solved by the generation that utilizes electricity production from the nuclear power stations.
- A decision on the design of the final repository for spent nuclear fuel shall not be taken until around the year 2000 so that it can be based on a broad body of knowledge.
- Technical solutions shall be arrived at within the country and foreign experience shall be used.
- The conduct of the work shall be guided by the regulatory authorities' continuous review of and directives for the work of the nuclear power utilities on the waste issue.
- The activities shall be conducted openly and with good public insight.

These general guidelines have guided SKB's continued work.

Studies of geological and hydrogeological properties and nuclide transport on a realistic scale were done during the KBS period in the abandoned Stripa Mine in Västmanland. The research at Stripa grew into an international project within the OECD/NEA. However, the groundwater conditions around Stripa were affected by the fact that the mine had been in operation since the Middle Ages. SKB therefore proposed in its R&D-Programme 86 that a new underground hard rock laboratory should be built in undisturbed rock.

In compliance with the requirements of the Nuclear Activities Act, SKB pointed towards the importance of alternative studies and reviewed the alternatives to the KBS-3 method in a background report to RD&D-Programme 86 /2-13/.

Most reviewing bodies found that the programme was well-balanced and complied with the requirements of the Nuclear Activities Act. Swedish organizations that are traditionally opposed to nuclear power, such as Avfallkedjan (the Waste Chain) and Folkkampanjen mot kärnkraft-kärnvapen (the Swedish Anti-Nuclear Movement), offered critical viewpoints.

SKI found that disposal of long-lived waste at great depth (several hundred metres or more) in continental geological formations is the only method judged to be available and feasible in Sweden in the foreseeable future. This method is also preferred by all countries who are conducting significant research and development in the waste field.

R&D-Programme 89 - 1989

In R&D-Programme 89, SKB maintained that final disposal of spent nuclear fuel can be accomplished in many different ways /2-14/. The method described in the KBS-3 report has been accepted by authorities and the Government as acceptable as regards safety and radiation protection. This method is therefore a reference alternative for continued studies of other interesting alternatives.

As a part of the programme that started in 1986, SKB made a comparison between KBS-3 and an alternative design called WP-Cave. WP-cave entailed packing the fuel relatively densely in the rock. The facility is therefore kept open for 100 years after closure and the canisters are cooled by air allowed to flow through the open deposition chambers. Another important difference between KBS-3 and WP-Cave is that the clay barrier in WP-Cave surrounds the entire repository instead of each canister. A higher temperature complicates the analysis of the chemical processes in the repository, and a larger clay barrier is more difficult to adapt to geological structures.

WP-Cave

Disposal method proposed as an alternative to KBS-3. The letters WP originate from the company name WP-system AB

As a result of the evaluation, SKB judged that it would be more difficult to demonstrate safety for a WP-Cave-type repository, at the same time as the costs would be higher. The studies of WP-Cave as an integrated system were therefore discontinued.

The studies of deep-hole disposal and its safety aspects that had been begun during the preceding period were projected to be completed in 1990 with compara-tive analysis with the reference concept, KBS-3. Furthermore, SKB mentions that a study in principle will be made of an alternative repository design, with deposition in long tunnels beneath the Baltic Sea.

In the research plan, SKB announced plans for a new safety assessment, SKB 91. The reason was the need for evaluating the importance of variations in the geological conditions for the performance and safety of the final repository.

Preliminary investigations for siting of an underground hard rock laboratory in the Simpevarp area were conducted and showed that the necessary conditions for such a facility existed on the island of Äspö, north of Simpevarp.

SKN (the National Board for Spent Nuclear Fuel) considered that SKB's timetables were not consistent with high flexibility in the programme, alternative repository solutions and public insight into the site selection process. SKN therefore proposed that SKB ought to investigate whether final disposal can be carried out stepwise with "checkpoints" and within the framework of this investigation plan for the construction of a demonstration facility. Such a facility could, for example, comprise 5–10 percent of a full-scale repository.

Several reviewing bodies emphasized how important it was that SKB's research and development should exhibit a broad choice of alternatives. SKN considered that SKB ought to continue its studies of the alternatives deep boreholes (Very Deep Holes) and long deposition tunnels (Very Long Holes) under the bottom of the Baltic Sea.

In the decision concerning R&D-Programme 89, the Government found that SKN's recommendations on safety assessment, canister design studies, underground hard rock laboratory and geological data for siting ought to be heeded. The research work ought to include an account and a follow-up of alternative management and disposal methods. No commitment should be made to a method until the safety and radiation protection aspects can be grasped.

A point of departure for continued R&D activities ought to be that a final repository for nuclear waste should be able to be put into operation in stages. In the next R&D-programme, SKB should explore the feasibility of incorporating a demonstration-scale repository in the work.

The Government also observed that the alternatives with Very Deep Holes and Very Long Holes beneath the bottom of the Baltic Sea being studied by SKB appear to be less suitable as final repositories. The Government shared SKN's view that good public insight is desirable in the process leading up to the choice of sites suitable for a final repository.

RD&D-Programme 92 - 1992

RD&D-Programme 92 is based on the same fundamental principles as previous programmes, but comprises an important concretization of the nuclear waste programme /2-15/. It presents a plan for realizing a deep geological disposal of encapsulated spent fuel. The strategy for the encapsulation plant is that it is to be built at the interim storage facility, CLAB. The programme comprised the start of the work of siting a deep repository. SKN's proposal that the repository should be built stepwisewas incorporated into the programme, in accordance with the wishes of the Government. Demonstration deposition of about 400 canisters, i.e. about 10 percent of the total number, is planned in an initial stage.

Only after this stage has been completed and evaluated will a decision be made on the continuation. It should then be possible either to continue along the beaten path or to retrieve the fuel.

Important inquiries that served as supporting documents to RD&D-Programme 92 were the SKB 91 safety assessment /2-16/ and the PASS report /2-14/, which compared different encapsulation methods and final disposal methods (KBS-3, Very Deep Holes, Medium Long Holes). The PASS report recommends a reference system according to KBS-3 with a copper canister with a steel insert.

SKI found in its evaluation of RD&D-Programme 92 that "SKI can accept that continued RD&D efforts be focused primarily on a method of the KBS-3 type. As far as SKI can see, based in part on participation in international cooperation, there is no method that appears to be substantially better from a safety viewpoint and that can be realized in Sweden without appreciably overstepping the time framework compared with SKB's plans". SKI also points out that "a stand in favour of the KBS-3 principle as a main strategy for the continued research programme should, however, not entail committing to the detailed design (canister design, repository depth, choice of geological formation) too early without a thorough and comprehensive grasp of the relevant safety and radiation protection aspects". Regarding PASS, SKI observes that "a number of reasons, most of which are safety-related, argue in favour of not having to study Very Deep Holes any further as an integrated system".

PASS
Project on Alternative Systems Study

KASAM recommended that SKB focus its RD&D activities on demonstration-scale disposal with the option of retrieval as an initial stage in the final disposal of the spent nuclear fuel.

In the Government decision of December 1993, the Government found, like SKI, that RD&D-Programme 92 meets the requirements of the Nuclear Activities Act. However, the authorities levelled criticism at certain unclear points in the programme. With reference to this criticism, the Government decision laid down certain requirements on a supplement to SKI as follows:

SKB should supplement RD&D-Programme 92 by giving an account of:

- the criteria and methods that can form a basis for selection of sites suitable for a final repository,
- a programme for description of the specifications for the design of an encapsulation plant and final repository,
- a programme for the safety assessments which SKB intends to prepare, and
- an analysis of how different measures and decisions influence later decisions within the final repository programme.

Supplement to RD&D-Programme 92

SKB submitted the supplement to RD&D-Programme 92 requested by the Government in August 1994 /2-17/. In May 1995 the Government found that SKB had supplemented RD&D-Programme 92 in compliance with the Government's request. They clarify that "the applications for a permit in accordance with Chapter 4 of the Natural Resources Act and a licence in accordance with Section 5 of the Nuclear Activities Act to erect a final repository for spent nuclear fuel and nuclear waste should contain material for comparative assessments which shows that site-specific feasibility studies, in accordance with SKB's reporting, have been conducted at 5–10 sites in the country and that site investigations have been conducted on at least two sites, and give the reasons for the choice of these sites", and that "SKB has, in a thorough manner, presented its view of criteria and methods for finding a site for the deep repository that is suitable from different aspects. The siting factors and criteria cited by SKB should, in the Government's opinion, serve as a point of departure for the continued siting work".

The Government also found that SKB, in order to provide a background and premises for the siting work, ought to present the results of its general siting studies and site-specific feasibility studies in a combined account in future RD&D programmes.

RD&D-Programme 95 - 1995

The emphasis in RD&D-Programme 95 /2-18/ is on how SKB plans to carry out the projects (encapsulation, deep repository) that are required to initiate deposition of encapsulated fuel according to the plans presented in RD&D-Programme 92. The programme also includes the supportive research and development needed for the projects and follow-up of and research on alternative methods. Important background documents for the programme included the following:

- The reports on the feasibility studies in Storuman and Malå.
- A nationwide survey of conditions and background for the siting work – General Siting Study 95.
- A template for safety reports, SR 95.

In its decision, the Government stated that SKB "shall in its continued R&D work carry out a system analysis of the entire final disposal system (encapsulation plant, transportation and final repository). This system analysis shall permit an integrated safety assessment of the entire final disposal system, including how principles for safety and radiation protection are practically applied in the safety assessment work. The system analysis shall also include an account of the alternative solutions to the KBS-3 method which SKB has described in previous research programmes or that have been considered in international studies. Different variants of the KBS-3 method should also be presented. The account shall further include the consequences of the case where the planned deep repository is not realized in any form (the zero alternative) as well as the on-going international work on transmutation".

In the reasons for its decision regarding RD&D-Programme 95, the Government said that before the site selection process can progress into site investigations on at least two sites, 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, after consultation with the national coordinator in the nuclear waste field appointed by the Government. Furthermore, SKB should be able, for the planned final disposal method, to stipulate criteria for evaluation of the sites and thereby specify which factors preclude further studies on a site".

For the feasibility study work, the Government assumes "that SKB, in consultation with concerned municipalities, will be given an opportunity to conduct site-specific feasibility studies in such a manner that a good body of data is available for SKB's consultations with SKI and SSI regarding the site investigations. SKB should take pains to ensure that concerned municipalities are given as much information as possible as a basis for their decisions in the siting work".

Heedful of the Government's decision on RD&D-Programme 95, SKB has in conjunction with RD&D-Programme 98 presented comprehensive material illuminating the points mentioned by the Government, i.e. alternative solutions to KBS-3, system analysis of the entire final disposal system, siting data and site selection criteria.

3 Deep disposal method

The main alternative for ultimate disposal of the spent nuclear fuel is to deposit it in a deep repository, approximately 500 metres down in the crystalline bedrock. The deep repository is the final link in a handling chain that starts at the nuclear power plants, continues with an interim storage period of about 30 years in CLAB, goes on to encapsulation in a special plant and is concluded with transport to the deep repository for deposition.

The handling chain is complete today up to and including interim storage in CLAB. The encapsulation plant and the deep repository remain to be built. Where the facilities are to be built, the pace at which this is to proceed and the detailed design of the facilities are questions whose answers will be optimized to obtain the best possible end result.

3.1 Planned deep disposal system

The most important components in the deep disposal system are the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB), the Encapsulation plant and the Deep Repository itself, see Figure 3-1. In addition, a system for transportation between the facilities is needed.

High-level waste requires both cooling and radiation shielding

Intermediate-level waste requires radiation shielding but no cooling

Low-level waste requires neither cooling nor radiation shielding

3.1.1 Waste

The waste to be deposited in the deep repository consists of spent nuclear fuel, which is both high-level and long-lived, as well as long-lived low- and intermediate-level waste.

Spent nuclear fuel

Most (about 99 percent) of the radioactive substances that are formed in a nuclear power plant are present in the spent fuel. When the fuel is removed from the reactor after 3–7 years it is highly radioactive and emits heat. The radioactivity comes mainly from fission products formed by nuclear reactions, but also from the transuranic elements that result when uranium absorbs

Fission products

Substances that arise during nuclear fission

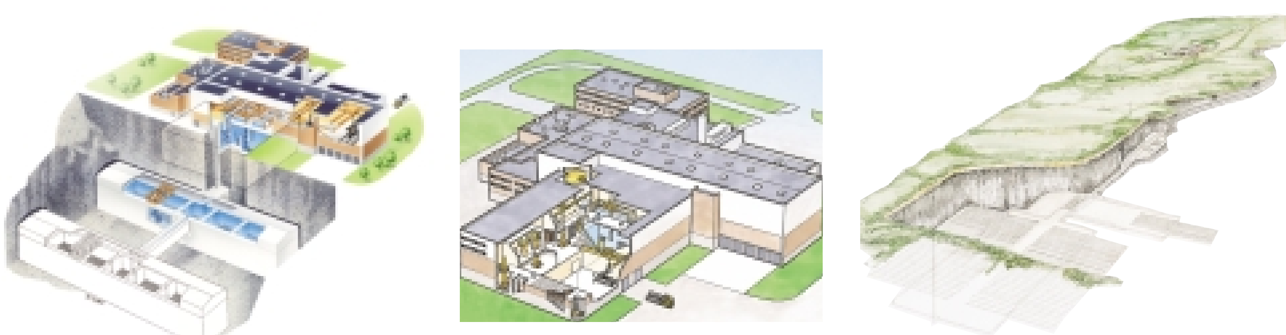


Figure 3-1. *Nuclear installations in the planned deep disposal system.*

Transuranic elements

Elements that are heavier than uranium

Core components

Control rods and other parts present inside a nuclear reactor

After interim storage in CLAB, the radioactivity of the fuel has declined by 90%

neutrons and forms heavier elements during reactor operation. Between 15 and 25 tonnes of fuel is consumed annually in a reactor. It is estimated that the Swedish nuclear power programme will produce about 8,000 tonnes of spent fuel, the exact quantity depending on how long the reactors are operated.

Long-lived low- and intermediate-level waste

Besides spent fuel, reactor operation gives rise to other long-lived waste. This waste may be deposited in the deep repository, separated from the encapsulated fuel, or at another location. The waste consists of core components and long-lived waste from research activities at Studsvik, among other things. The content of long-lived radionuclides in this waste is too great for it to be deposited in SFR. Altogether, it is estimated that this low- and intermediate-level waste (LILW) will occupy about 25,000 m^3 in the repository. This includes short-lived operational waste from CLAB and the encapsulation plant that arises after SFR has been closed.

3.1.2 CLAB

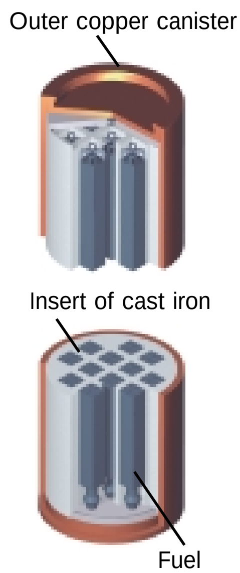


Figure 3-2. *Canister for spent nuclear fuel.*

The spent nuclear fuel from the Swedish NPPs is being stored today in the Central Interim Storage Facility for Spent Nuclear Fuel, CLAB, at the Oskarshamn Nuclear Power Station. Before the fuel is transported to CLAB, it is stored at the NPPs for at least nine months.

The fuel is stored in water-filled pools, situated in rock caverns at a depth of about 30 metres. Plans call for the fuel to be stored for about 30 years before it is emplaced in the deep repository. During storage the level of radioactivity in the fuel, and thereby its heat output, declines by about 90 percent.

3.1.3 Encapsulation plant

Prior to deep disposal, the fuel is encapsulated in leaktight copper canisters, see Figure 3-2. This is done in an encapsulation plant.

SKB plans to co-site the plant with CLAB. That will permit coordinated operation and avoid the necessity of off-site transport. If the plant is located in connection with the deep repository or elsewhere, the unencapsulated fuel will be transported from CLAB to the encapsulation plant in a manner similar to today's shipments of spent nuclear fuel from the NPPs to CLAB.

3.1.4 Deep repository

Ten percent of the spent fuel is deposited in an initial stage

The encapsulated fuel will be transported to the deep repository in robust casks similar to those used for today's fuel shipments, see Figure 3-3. In the main alternative, the deep repository consists of a system of deposition tunnels at a depth of 400–700 metres. The canisters with fuel are emplaced one by one in deposition holes in the floors of the tunnels. Each canister is surrounded by blocks of compacted bentonite clay.

SKB plans to implement deep disposal in two stages. In the first stage we will demonstrate that the deep disposal method works. Approximately 400 canisters of spent nuclear fuel – equivalent to about ten percent of the total quantity – will be deposited in this first stage.

When deposition has been demonstrated, the results will be evaluated before a decision is taken on further construction and deposition of the remaining waste. All other available knowledge on different methods of managing and disposing of the spent fuel will then also be evaluated. The already deposited waste can

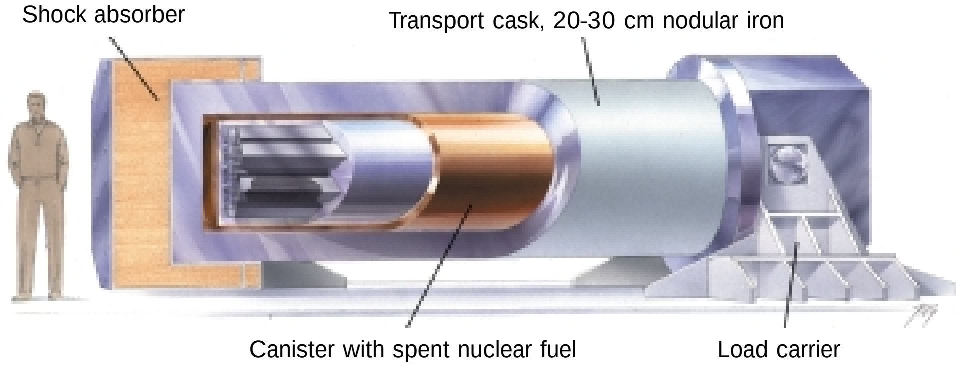


Figure 3-3. *Transport cask for canister with spent fuel.*

also be retrieved for other treatment if so desired. This would require new facilities, among other things for interim storage of canisters. Retrieval of en-capsulated fuel remains possible during continued deposition and a long time after the deep repository has been closed and sealed. The effort needed for retrieval will, however, increase with the passage of time.

After the first stage of the deep repository, an evaluation is performed. It is possible to retrieve the waste if the evaluation has a negative outcome

Long-lived LILW will be transported to the deep repository in basically the same way as encapsulated fuel. According to the plans, deposition will not be started until after completion of demonstration deposition and evaluation.

3.2 System analysis

The Government wrote in its decision regarding RD&D Programme 95 that SKB must "carry out a system analysis of the entire final disposal system (encapsulation plant, transportation and final repository). This system analysis shall permit an integrated safety assessment of the entire final disposal system, including how principles for safety and radiation protection are practically applied in the safety assessment work".

SKB has therefore conducted a system analysis that provides an integrated account of the entire deep disposal system /3-1/ (interim storage facility, encapsulation plant, transportation and deep repository). Furthermore, we have investigated the "consequences of the case where the planned deep repository is not realized in any form (the zero alternative)" /3-2, 3-3/, as also requested by the Government.

The main purpose of the system analysis is to show that operational reliability is ensured in all parts of the system. Another purpose is to show that the system provides a reasonable balance between the measures at different steps in the process and the resulting long-term safety. For example, a balance must be found between measures that are adopted during operation and give rise to a radiation dose to the personnel and any improvements in long-term safety which these same measures give rise to. The analysis should also reveal the relationships that exist between the different steps in the system and how these relationships affect safety in different stages. Obvious relationships exist, for example, between quality control in the fabrication of empty canisters, reliability in sealing of the canisters, the risk of damages during handling and transport of the canisters, and the long-term performance of the canisters in the deep repository. Long-term safety is also related to how well the operation of the deep repository is managed.

The system analysis should also examine the degree of flexibility in the system when it comes to technical design details, time schedules, siting or changes in the strategy of the waste programme. The analysis should also shed light on how different variations in system design influence short- and long-term safety. Impacts in the form of other environmental consequences and conservation of natural resources are also examined.

3.2.1 Safety

- How much should the waste be treated?
- When should the fuel be transferred from the interim storage facility to the final respository?
- How do we assess future risks?

A deep repository has a phase consisting of active measures (construction, operation, maintenance) and a passive phase after closure of the repository when no additional measures are needed. The safety requirements must be fulfilled during both phases. This necessitates trade-offs between safety during operation and post-closure long-term safety. Some examples of this are the following:

- Extensive treatment of waste gives rise to more risks during handling, but generally leads to reduced long-term risks for the deposited waste. A reasonable balance must be achieved.
- Storage in a monitored repository provides a high degree of control and safety. If control and monitoring should for some reason fail, however, the risks are considerably higher than if the waste had been emplaced in a closed repository. A suitable time must therefore be found to transfer the fuel from a supervised interim storage facility to a closed deep repository.
- The assessment of risks at various points in the handling process is more or less reliable. In general, reliability is lower when it comes to assessing events far in the future. These aspects must be taken into account when striking a balance between long-term and short-term safety.

Safety during operation

As a basis for the system assessment, SKB has analyzed safety during the operation of the different parts of the system (encapsulation, transport, deep disposal) /3-4, 3-5, 3-6/. The analyses cover both normal operation and the risks of mishaps.

The radiation dose to which a person is exposed is given in mSv (millisieverts)

The entire system is designed to ensure the safety of the personnel and minimize the dose load. Releases via water and air to the environment must be kept to a low level, as must the quantity of radioactive waste from the activities. Risks to the personnel and the environment must be minimized.

Natural background radiation contributes about 1 mSv/y on average in Sweden

Experience from CLAB and calculations for other facilities indicate that the individual doses to the personnel will amount to 1–1.5 mSv/y during normal operation of the planned facilities. Small releases of radioactive substances via water and ventilation air take place today from CLAB and will also take place from the encapsulation plant. During the past ten years, the releases from CLAB have been a few ten-thousandths of the level permitted from a nuclear installation. The releases from the encapsulation plant are expected to be of the same order of magnitude.

Analyses of mishaps and disturbances show that releases of radioactivity to the environment can follow upon accidents caused by e.g. mechanical damages to the fuel or a large fire. The consequences for the environment are estimated to be radiation doses in the order of a few thousands of a mSv. The restoration work following a mishap may lead to elevated doses to personnel and an operational disturbance of varying duration.

The conclusion is that the system for management and disposal of spent nuclear fuel and other long-lived waste is designed for the large quantities of radioactivity present in the spent fuel. This means that doses to personnel and releases to the environment will be able to be kept well within permitted limits. This applies to both normal operation and abnormal occurrences.

Long-term safety

The long-term safety of the deep repository is a key question for the entire deep disposal system. A special chapter, Chapter 4, is therefore devoted to the principles of achieving long-term safety. Chapter 8 shows how long-term safety is evaluated by means of safety assessments. Both SKB and SKI have carried out large such assessments /3-7, 3-8, 3-9/. SKB intends to present a new safety assessment in 1999 (SR 97).

The safety assessments that have been carried out have shown that it is possible to build a deep repository that meets the stipulated requirements as regards the long-term safety of the repository. The siting process will yield site-specific data that can be used for detailed analyses of how well different sites are suited for a deep repository. In this way the safety assessments will be an important source of information for both SKB and the regulatory authorities for making different decisions in the siting work.

3.2.2 Freedom of choice

Technical flexibility allows freedom of choice on both siting and design

The deep disposal system is flexible as regards siting of facilities, design and timetables for execution. This flexibility is important, since it offers freedom of choice in the work of finding a satisfactory and broadly accepted solution to the waste problem.

The encapsulation plant will, according to the main alternative, be sited at CLAB. This offers considerable coordination gains and simpler handling compared with other alternatives. However, a siting at the deep repository, at another nuclear installation or at another location altogether is quite possible.

The siting of the deep repository is in progress, and the site screening and selection work is proceeding in a step-by-step manner. The studies that have been carried out show that suitable rock may exist at many places in most parts of the country. Feasibility studies in individual municipalities located in several parts of the country have identified areas that can be of interest for site investigations. Thus, all signs point towards considerable freedom of choice in the siting of the deep repository. Based on the feasibility studies, SKB plans to conduct site investigations at a minimum of two locations in the country.

The deep repository is technically flexible in that several aspects of the design can be varied. These include location at different depths, different ways of connecting the deep repository with the surface installations, and different arrangements of canister positions in the tunnel systems.

This technical flexibility contributes to freedom of choice in siting, since the repository can be adapted to different local conditions. The technical designs will be finalized in the applications for permits to build the encapsulation plant and the deep repository.

Interim storage in CLAB permits a flexible timetable for siting and building the deep repository

The timetable for siting and building the deep repository contains considerable uncertainties. It is, for example, difficult to estimate the time needed for the important public discussion that is required at several stages of the siting process. The time required for licensing is also difficult to estimate. The application must be reviewed under several laws, and these reviews can often not be done simul-taneously. It is therefore important to be able to cope with delays in the time-tables. Since the interim storage period in CLAB can be extended relatively easily, there is also the necessary flexibility in time.

3.2.3 Long-term storage in CLAB - the zero alternative

The CLAB facility was built to be operated for about 60 years, from the start in 1985 until all fuel has been taken to encapsulation and deep disposal in the middle of the next century. The spent fuel will then have been stored for about 30 years, on average. SKB has also studied the consequences of continued storage in CLAB /3-2/. The analysis includes both the long-term properties of the fuel and the long-range durability of the facility.

The study shows that it should be possible to extend the storage time to a hundred years or more, provided that storage takes place under controlled forms, i.e. with operation and supervision as today and with suitable maintenance. Safety in CLAB requires, for example, reliable cooling of the fuel. If, for some reason, it should be necessary to abandon CLAB without sustained cooling – war, for example – the consequences could be serious /3-3/.

3.2.4 Safeguards and physical protection

Through international treaties such as the Nuclear Non-Proliferation Treaty, the Euratom Treaty and other bilateral agreements, Sweden has undertaken to use nuclear materials for peaceful purposes only. Sweden has also undertaken to keep records of all handling of nuclear materials, including spent nuclear fuel, and to submit to international inspections. Handling of spent fuel is subject to IAEA rules regarding safeguards. Handling of nuclear materials is also monitored by Euratom and SKI.

IAEA
International Atomic Energy Agency

Established procedures exist for handling of spent fuel at the NPPs and CLAB. All measures are documented, and the IAEA frequently performs inspections, sometimes unannounced. Such inspections are facilitated by the fact that the fuel is always accessible for verification and measurement. After encapsulation this becomes more difficult, requiring other inspection procedures. Existing safeguards technology can for the most part be used for the encapsulation plant.

Safeguards
System intended to discover in time whether a country is trying to divert nuclear material for the manufacture of nuclear weapons

In the case of deep disposal, some new questions arise. The IAEA has written a draft policy for safeguards for deep repositories. There it is stated that safeguards should be maintained even when the repository has been backfilled and sealed. This control should be maintained as long as safeguards are being applied at other points in the nuclear fuel cycle. Safeguards during operation should be based on verifying the design of the repository and the flow of material to and from the repository. After closure of the repository, it should be possible to check by surveillance from the surface or the air by photographing and by onsite inspection.

A proposal for how safeguards for encapsulation, transportation and deep disposal can be designed in practice is presented in /3-1/.

All handling of the fuel is surrounded by physical protection. The physical protection consists of the guarding and other security measures taken to protect the fuel from theft or sabotage.

Part Ⅱ - Execution

5 Programme overview
6 Siting
7 Technology
8 Safety assessments
9 Research
10 Decommissioning

5 Programme overview

So far we have described the actual premises for the nuclear waste programme: the legal framework, the past history with important Government decisions and choices of direction, the existing facilities, the alternative courses of action in the future, the deep disposal method and the reasons why it is SKB's main alternative.

Based on these premises, SKB has drawn up guidelines for the future and formulated the programme. As before, deep geological disposal is the main strategy, at the same time as we are preserving our freedom of choice by following and exploring other alternatives. This is in line with the Government's decision on RD&D-Programme 95.

The programme overview provides an overview of the entire programme, the long-range goals and the concrete plans for the immediate future.

5.1 What does SKB want?

5.1.1 Method

In order to be able to go on and dispose of the spent nuclear fuel in a long-term safe manner, SKB deems that work on the deep geological disposal method should be continued so that it can be implemented practically in an initial stage. Studies of other methods should also be pursued, for example by SKB's participation in an international exchange so that we can learn from and assess the development work being done in other countries.

The initial stage entails deposition of about 10 percent of the spent fuel, equivalent to about 400 canisters. Before a decision is taken regarding continued deposition, a thorough evaluation will be made of experience from the first stage and other new-found knowledge. Provisions will be made to permit retrieval of the nuclear fuel after disposal, if a better way of disposing of or reusing it is found in the future.

Demonstration deposition of 400 canisters followed by thorough evaluation

5.1.2 Timetable

In order to realize the ambition of demonstrating deep disposal in an initial stage, SKB needs to be able to:

- Site and build the necessary facilities.
- Encapsulate, transport and deposit the waste.
- Analyze and describe safety issues and environmental consequences.

This can in large part be done on the basis of established knowledge and proven technology. However, new knowledge and technology are needed in certain areas.

The work must be pursued with high intensity. This is the best way to take advantage of the competence and resources now available and to concretely discharge the producer responsibility borne by the nuclear power industry under the Nuclear Activities Act. However, sufficient time should be allowed for the democratic decision process in the affected regions and municipalities, as well as for a thorough EIA process. We estimate that encapsulation and deposition in an initial stage can be commenced in about 15 years.

Deposition will begin in about 15 years

5.1.3 Siting

Siting of the deep repository must be based on a broad body of background material. An important goal in the siting work is to initiate more feasibility studies. More than before, a regional perspective must guide the work, since the establishment of a deep repository influences and needs to draw on the skills and resources of an entire region. Before undertaking a discussion concerning a feasibility study, a regional body of data must be available and a clear reason must exist why the municipality in question is of interest. Furthermore, feasibility studies must be done in collaboration with the concerned municipality.

Regional studies starting on the east coast

Regional studies of geology, land use and infrastructure are being conducted in all counties of potential interest, starting with the counties along the east coast. The studies are being followed up with presentations of findings and discussions in the counties in question, giving municipalities an opportunity to cooperate on the deep repository issue. We believe that this modified strategy can provide a new point of departure for feasibility studies. At the same time, the comparison material for choice of areas for site investigations is broadened. Ongoing feasibility studies will continue to be pursued with high priority.

5.1.4 Democratic consensus and community support

Realizing the deep disposal project requires the support of the community and a democratic process in reaching all important decisions. To obtain this support, SKB's work must be of high quality and must be reported in an open and objective manner. Furthermore, it is necessary that the programme, including the need for more feasibility studies, receive the clear and outspoken support of the national authorities, since it is ultimately a national responsibility to dispose of the nuclear waste. Much better forms for the siting work and financial support to the municipalities exist now than a few years ago. Clarification is still needed on some points, however. For example, the government authorities need to clarify how support to the municipalities is to be provided after the feasibility study phase. SKB will continue its efforts to obtain a broad and active consensus in the community on the nuclear waste issue.

Our plans

- Demonstration of deep disposal
- Research on performance, safety and other methods

5.1.5 Research, development and demonstration

Guided by the main strategy described above, SKB's research, development and demonstration work will include the following components:

- A step-by-step programme for demonstrating deep geological disposal of encapsulated spent nuclear fuel.
- A programme for research and development around central issues relating to performance and safety for the main method as well as for other methods of interest.

SKB's plan is thus to concretely demonstrate deep disposal of encapsulated spent nuclear fuel. At the same time we will conduct research and development that also explores other methods. When the demonstration is completed it will be evaluated. Only then can a decision be made on how the work should proceed, see Figure 5-1.

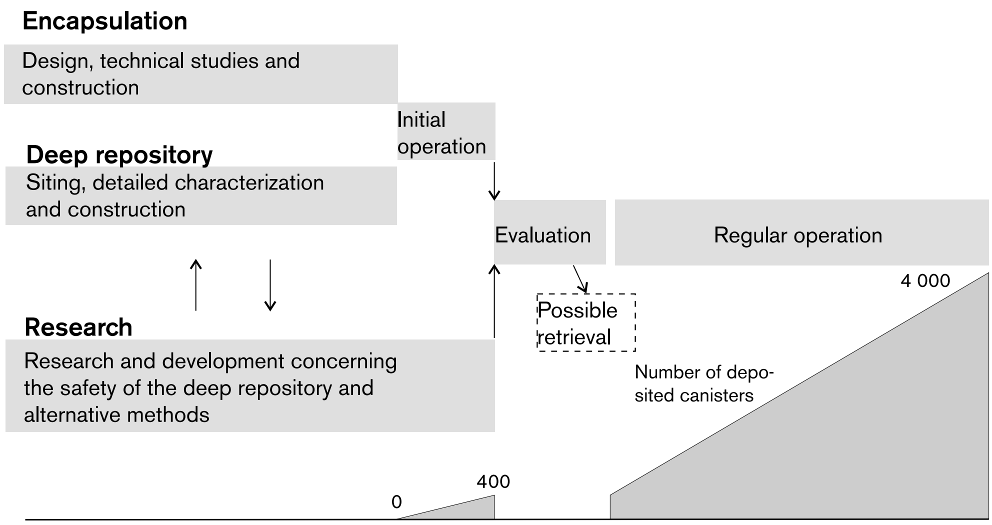


Figure 5-1. *Important steps in the deep disposal system.*

5.2 Goals of the work of the next few years

Based on the overall plan of action, SKB has formulated goals and programmes for the coming six-year period. More detailed plans have been made for the first three years.

Our goal

At least two sites will have been selected for site investigations by 2001

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 general siting studies for all counties in Sweden except Gotland.
- Report the results of the feasibility studies in Nyköping, Östhammar, Oskarshamn and Tierp.
- Conduct and report the results of at least one more feasibility study.
- Submit an integrated report of all siting data for the deep repository.
- Present programmes for geoscientific site investigations and site evaluation with criteria.
- Choose at least two sites for site investigations and submit site-specific investigation programmes.
- Submit a new comprehensive assessment of long-term safety and have it reviewed by international experts.
- Continue the work of supportive research on the main method and alternative methods for managing and disposing of spent nuclear fuel.
- Continue the work of technology development and planning/design of encapsulation and deep disposal.
- Compile supporting material for an application for a permit to build an encapsulation plant.

The transition to site investigations is an important step in the nuclear waste programme. It is not associated with any formal licensing process, but in practice both SKB and the concerned municipalities need to know the attitude of the authorities towards SKB's commencement of investigations on the chosen sites. This can be provided by having SKI, after consultations with SSI and others, state its opinion of SKB's total supporting documentation for both method and siting, and indicate what they think of the choice of sites and investigation programme. Such a statement will presumably be needed in order for the concerned municipalities to adopt a position on a site investigation.

During the second half of the coming six-year period we plan to carry out the following:

- Commence site investigations on at least two sites.
- Update the safety assessment and the system analysis, among other things by utilizing data from the investigation sites.
- Apply for a permit to build the encapsulation plant.

5.3 How will SKB achieve its goals?

Following is an overview of state of knowledge, key issues and how SKB plans to go about achieving the goals we have formulated. The plans are presented in more detail in Chapters 6–10. Figure 5-2 shows a general timetable and activity plan for the coming three-year period.

5.3.1 Siting and establishment

New facilities
- Canister factory
- Encapsulation plant
- Deep repository

Before a complete system for disposing of all nuclear waste in Sweden can be put into operation, SKB needs to site and build two new nuclear installations: an encapsulation plant and a deep repository. Furthermore, a plant for fabricating canisters is needed. Preliminary estimates of costs and personnel requirements for these facilities are given in Figure 5-3.

Depending on the siting of the deep repository, investments may also be needed in infrastructure (railway, road, harbour with terminal area for transloading to road or rail transport). An overview of the work of siting and establishing the deep repository and the encapsulation plant is provided in the following.

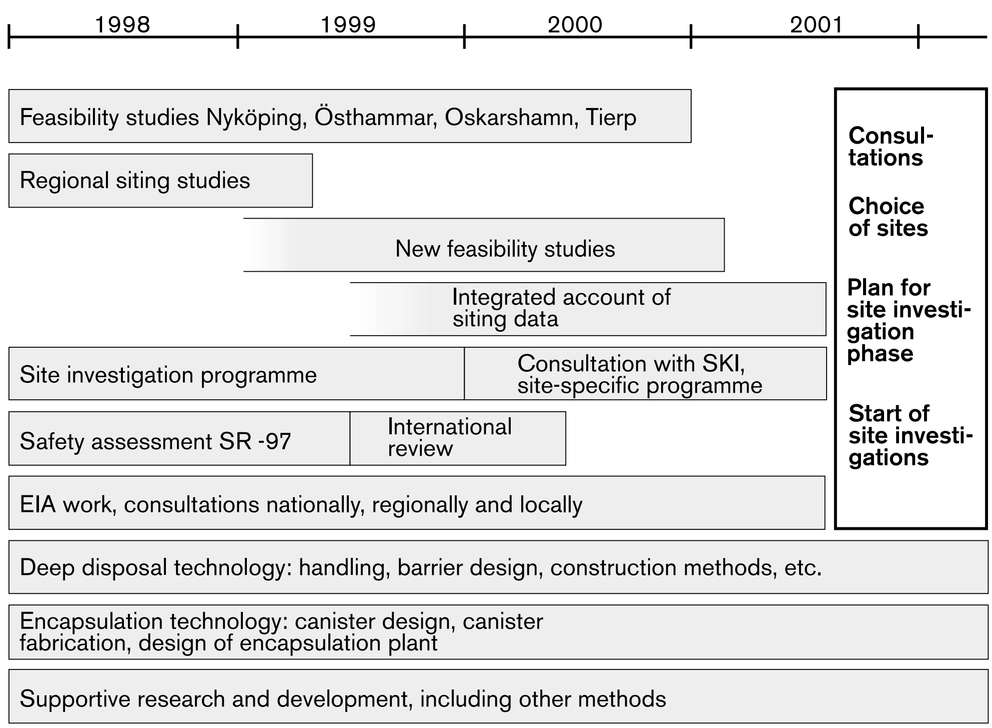
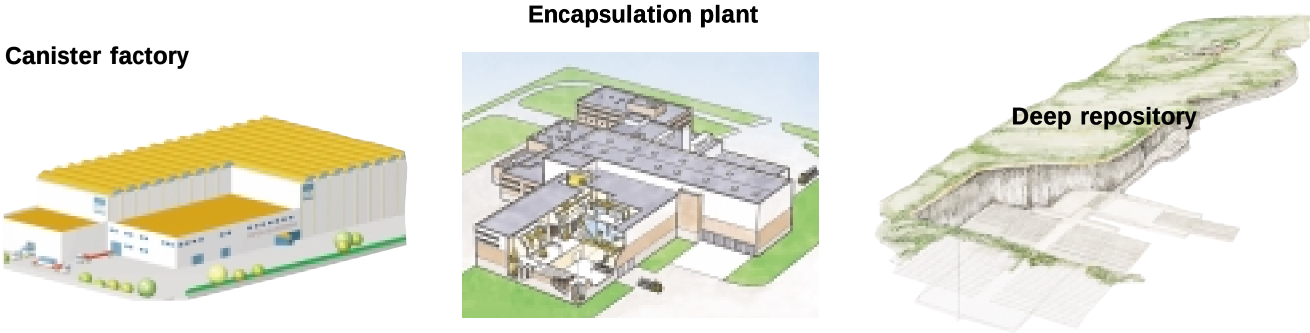


***Figure 5-2.** General timetable and activity plan for the coming three-year period.*



	Canister factory	Encapsulation plant	Deep repository
Investment and operation	about SEK 4 billion	about SEK 3 billion	about SEK 13 billion
Number of employees	about 30	about 40	about 220

Figure 5-3. *Remaining facilities for management and disposal of nuclear waste.*

Siting of the deep repository is a key question in the nuclear waste programme. A determined and transparent siting process is necessary for arriving at a good solution. In conjunction with RD&D-Programme 98, SKB is publishing reports on the first ten regional general siting studies and initiating determined efforts to bring about more feasibility studies. For the encapsulation plant, SKB plans a co-siting with CLAB, since this offers several obvious advantages, see Chapter 7. Alternative sitings, for example at the deep repository, will also be analyzed in the course of the EIA process.

The process leading up to an ultimate disposal of spent nuclear waste executed in this fashion is long and comprises many steps. Figure 5-4 shows the various steps for siting, construction, operation and closure of the planned system. SKB must apply for a permit for each facility and for each and every one of these steps. The decisions are made by the Government, and approval must be obtained from the safety, radiation protection and environmental authorities, as well as the concerned municipality, in order for SKB to proceed from one step to the next.

It is valuable if the encapsulation plant and deep repository projects can be pursued independently. However, the facilities must function in concert, and one project should not be carried too far before it is clear that the other can also be realized. The licensing processes for the two facilities are therefore linked to each other. How these links are to be regulated has been discussed. SKB finds the following conditions to be appropriate:

- Site investigations for the deep repository must have been commenced before a siting permit application is submitted for the encapsulation plant.
- A siting permit application for the deep repository must have been submitted before a permit is granted for siting and construction of the encapsulation plant.

In practice, the authorities will also regulate these questions when the permits are issued by setting up conditions for the continued work.

Deep repository

Before the Government considers and rules on the siting of the deep repository, SKB will conduct general siting studies, feasibility studies and site investigations. Decisions concerning these activities have different implications and dignity. This is illustrated in Figure 5-5.

General siting studies entail regional (county) or nationwide compilations and analyses of existing data which can be of interest for judging siting conditions in different parts of Sweden. General siting studies are initiated and conducted by SKB as a part of the regular programme.

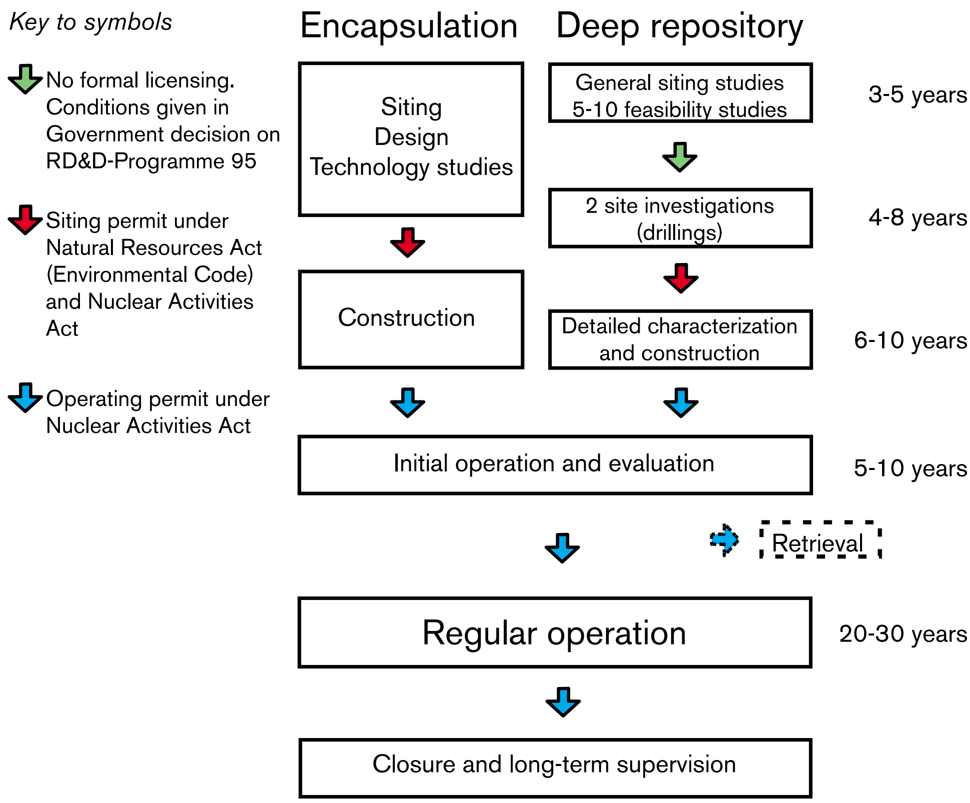


Figure 5-4. *Important steps and licensing procedures.*

General siting studies
Feasibility studies
Site investigations

↓

Decision on where the deep respitory will be sited

↓

Detailed characterization and construction

Initial operation

Regular operation

Closure

Feasibility studies are data compilations and analyses on a municipal scale. Existing information is compiled as in the general siting studies, but the feasibility studies are conducted on a more detailed scale. The feasibility studies not only provide data on the bedrock, but also on land use, environmental impact, transport prospects and societal conditions. Areas that can be of interest for further studies are identified. Altogether, SKB intends to carry out between five and ten feasibility studies.

In actuality, a feasibility study sets a consultation (an EIA process) in motion in which not only the municipality and the public, but also the county administrative board, neighbouring municipalities, safety authorities and other authorities take part. A feasibility study can in principle also be initiated and conducted by SKB without the consent of other parties. However, we have chosen not to conduct feasibility studies in municipalities that oppose them. A basic prerequisite for a feasibility study to be conducted is also that SKB, after a general appraisal of what is known about the bedrock and other factors, arrives at the conclusion that there may be areas of interest in the municipality.

At least two site investigations where extensive investigations are made of the bedrock

Site investigations entail extensive investigations of the bedrock using boreholes down to a depth of one kilometre. In this phase, detailed studies are also made of how the facilities and transportation can be designed and executed and what the environmental consequences will be. SKB plans to investigate at least two sites in the country.

Decisions on site investigations are in the formal sense primarily a matter for SKB and the landowner. However, as a consequence of the policy of transparency and the requirement on local acceptance which SKB has chosen for the siting process, we will only conduct a site investigation if this meets the approval of the municipality. A site investigation entails a more extensive local establishment and has certain physical impacts in the form of boreholes and field activities lasting several years. In practice, the start of site investigations is therefore an important

	General siting study	Feasibility study	Site investigation	Detailed characterization
Legal	None	None	Small	Big
Physical	None	Local office	Borehole, road...	Tunnel/shaft
Financial magnitude	SEK 1m	SEK 10m	SEK 100m	SEK 1,000m
Political/public opinion	None	Big	Big	Big

Figure 5-5. *Different decisions and their implications in siting of the deep repository.*

stage in the siting process. In its decision on RD&D-Programme 95, the Government set up conditions for SKB's presentation of its findings prior to this stage.

It is not until after site investigations and prior to a ***detailed characterization*** on a site that the formal decision on siting of the deep repository is made. All work prior to this decision (general siting studies, feasibility studies, site investigations) is supposed to contribute towards the preparation of a thorough environmental impact statement (EIS). Besides describing the environmental consequences of a deep repository on the selected site, an EIS is also supposed to describe alternatives for siting and alternative methods for disposing of the nuclear fuel waste. Regardless of how the authorities and municipalities have taken part in the environmental impact assessment (EIA) process, they must make a thorough appraisal of the matter when the application with all its supporting documentation is submitted by SKB.

Detailed characterization
Very detailed investigation of the bedrock on a site that is a final candidate

When the detailed characterization has been completed and the results reported and evaluated, and when most of the construction work for the initial operation of the deep repository has been finished, two very important permits are required:

- Permit to begin encapsulating spent nuclear fuel in canisters.
- Permit to begin depositing canisters in the deep repository.

Since these activities are closely linked to each other, the two decisions will probably be made simultaneously or with a short interval. Only then does SKB have permission to do something which concretely entails that the spent nuclear fuel will eventually be emplaced in a deep repository.

When an operating licence has been obtained, initial operation can commence. This operating period will be followed by an evaluation. After the evaluation comes a new big decision to determine how the programme is to be carried further. The work up to this point in time thus entails that we concretely execute an initial stage (demonstration) of deep disposal, in parallel with a continued programme of research and development, also covering other alternatives.

Encapsulation plant

SKB plans to build the encapsulation plant at CLAB

As mentioned previously, the main alternative for siting of the encapsulation plant is adjacent to the existing interim storage facility CLAB in the municipality of Oskarshamn. Another alternative is co-siting with the deep repository. Other locations may also be considered. The planning and design process is based on a co-siting with CLAB, but the layout of the facility permits it to be adapted to other sites as well. Advantages and disadvantages of different sitings will be explored in the environmental impact statement (EIS) which SKB will submit together with the siting permit application.

Canister factory

Empty canisters will be fabricated in a special factory. The siting of the canister factory has not yet begun. One possibility is to co-site it with an existing metalworking plant on completely commercial terms. Alternatively, it can be located in the same municipality/region as the encapsulation plant or the deep repository. In order for the latter alternative to be of interest, it is necessary that industrial capacity and interest in the canister factory exist.

Timetable for construction and operation of facilities

Figure 5-6 provides an overall picture with a timetable of how we plan to construct and operate the encapsulation plant and the deep repository. It is estimated that the initial operation of the deep repository can begin around 2012, which is a few years later than was assumed in RD&D-Programme 95. The postponement in the timetable is due to the fact that feasibility studies and other siting work takes longer than was previously assumed. The timetable up until a siting permit has been obtained for the deep repository is uncertain. Siting may therefore take longer than indicated here.

5.3.2 Technology for encapsulation and deposition

Fabrication and sealing of the canister are key questions

Practical experience of handling, treatment and transport of spent nuclear fuel and other nuclear waste dates back several decades in Sweden and other countries. The methods used work well and do not require any major development in the next few years. Experience of encapsulation and deposition of spent fuel does not exist today, however. How the canisters are to be designed, fabricated, sealed, inspected and deposited are therefore key questions in the technical development programme.

Encapsulation

SKB has conducted research to study the durability of the copper canister since the end of the 1970s. The research results generally show that the planned canister can meet the requirements. Technical development work is also being carried out to enable canisters to be fabricated on an industrial scale. In recent years, all components of the canister have been trial-fabricated on full scale by means of different methods.

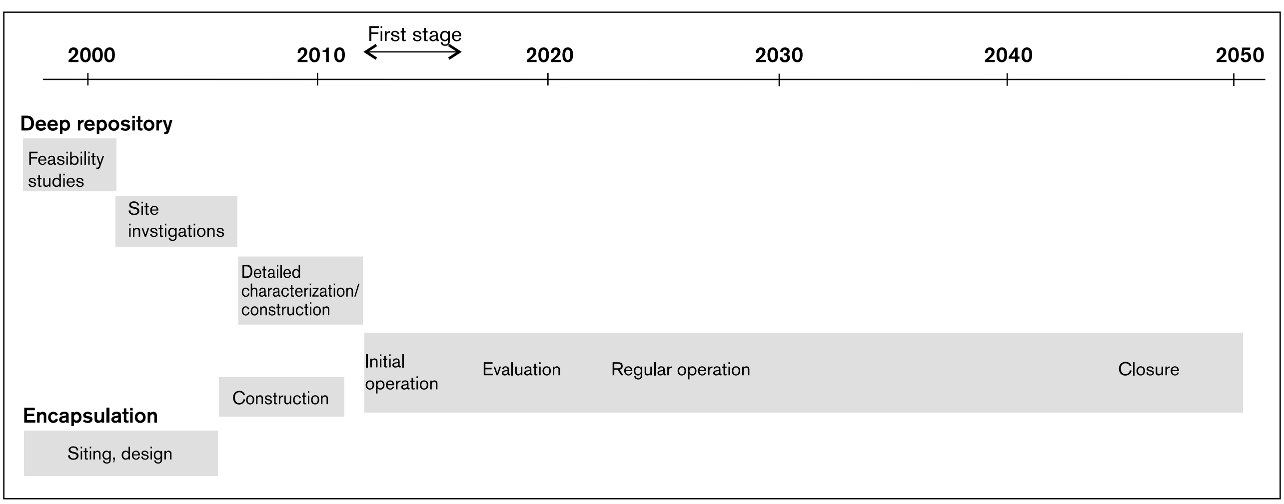


Figure 5-6. *Timetable for siting, construction and operation.*

Different methods for canister fabrication will be further developed in the coming years. When a final fabrication method is to be chosen, SKB must have tested and specified all fabrication steps and the system for quality assurance must have been certified according to international standard. Technical documentation for a canister plant must be available.

To meet the need for canisters for full-scale tests at the Äspö HRL, a couple of complete canisters will be fabricated in 1998. At least six more canisters will be fabricated for the same purpose in 1999. Copper tubes and copper lids for the canisters will be fabricated to meet the needs of the Canister Laboratory.

During the next few years, SKB will survey and assess suppliers on the market for the purpose of finding the best suppliers and forging long-term relations with them. SKB plans to implement a quality system that covers the entire chain from material suppliers to deliveries of finished canisters.

In RD&D-Programme 95 we described our plans for building a laboratory for encapsulation technology. Such a laboratory has now been built in Oskarshamn and will start operation in the autumn of 1998. The Canister Laboratory will serve as a centre for development of encapsulation technology and training of personnel for the encapsulation plant. The main purpose is to test equipment for sealing and inspection of canisters. This is needed in order to obtain a good basis for the continued planning and design of the encapsulation plant. In the Canister Laboratory, SKB plans to demonstrate that canisters can be sealed with the requisite quality at the production pace that will be required in the encapsulation plant. The results from the Canister Laboratory will constitute an important part of the permit application for the encapsulation plant.

The Canister Laboratory started operation in the autumn of 1998. It will be a centre for development and training

In summary, the plans for development of the encapsulation technology entail that SKB plans to do the following during the next three years:

- Continue full-scale trial fabrication of canisters and choose a fabrication method. All parts will be fabricated in such quantities that various fabrication methods can be tried out and optimized.
- Further develop the technology for sealing and testing of canisters in the Canister Laboratory. The programme for the period up to 2001 includes trial sealings of around a hundred copper lids. Equipment for nondestructive testing will be tried out to make sure it meets the requirements for detection of defects.
- Test and demonstrate other parts of the encapsulation process in the Canister Laboratory. An example is handling in the encapsulation plant's handling cell.
- Compile supporting documentation for an application for a permit to build the encapsulation plant.

Development of technology for encapsulation

- Fabrication
- Sealing
- Quality assurance

During the subsequent three-year period, we plan to do the following:

- Continue the basic design work and apply for a permit for the encapsulation plant.
- Describe the detailed design and methods for fabrication of the canister.
- Test and verify methods for both nondestructive and destructive testing. This can be conducted at the same time as the licensing process for the encapsulation plant.

Construction of facilities

Extensive knowledge is available as a basis for building the encapsulation plant and the deep repository. Experience from the NPPs and CLAB can be drawn on to design and build the encapsulation plant and the deep repository's surface facilities. As far as the underground portion of the deep repository is concerned, considerable knowledge exists from the mining industry and underground rock facilities for civilian and military purposes. SKB has direct experience from the rock facilities at CLAB, SFR and the Äspö HRL. Taken together, this provides a broad knowledge base which can be utilized to design and build the deep repository's underground portion.

The special requirements made on the deep repository are such that on some points new technology or modification of existing technology is necessary. This is above all true of methods for building and grouting tunnels, technology for making deposition holes, and methods for judging rock conditions from a construction point of view. SKB is conducting technology development around these questions, the results of which will gradually be added to the accumulated planning of the deep repository.

For the deep repository, the coming period entails continued work on planning/design and technology development. The planning and design work will be adapted to the siting work. With a planned start of site investigations in 2002, this means that the planning and design work during the coming three-year period will be based on general data on the bedrock and existing plant descriptions, unrelated to any particular site. Development of construction technology will proceed in parallel.

Site-specific design of the deep repository when results are available from site investigations

Within the next six years, the site investigations are expected to get under way and progress to a point where the design work can be based concretely on data from the sites being investigated. The goal is to be able to present a general, site-specific design of the deep repository facilities for the specific sites in question. Before then, schematic solutions will be established for important subsystems, such as the transportation system, access options to the underground facilities, and construction methods for the tunnels.

Deposition of waste

At the deep repository, the canisters will be received and taken down to their respective deposition holes. Radiation shielding will be provided all the way down to deposition. The canisters can be handled using available technology and without exposing the personnel to harmful radiation levels.

Äspö HRL

Centre for development, testing and demonstration of deep disposal

The activities associated with deposition of canisters and backfilling are in large part unique to the deep repository. Technology therefore needs to be developed for transferring the canisters to handling machines in the deposition tunnels, emplacing them in deposition holes and then applying the bentonite blocks that will serve as a buffer around the canisters. Fabrication and transport of bentonite blocks, as well as backfilling and sealing of tunnels, are also areas where technology needs to be developed and tried out.

Within six years we will be able to demonstrate the deep disposal technology in its entirety

The work of technology development for deposition has been under way for a long time. The full-scale trials that are now planned at the Äspö HRL entail a new step in this development. In these trials, components developed individually so far will be integrated in a whole system which will be tested in a realistic environment and on a full scale. The Äspö HRL will thereby become the central resource in our work of developing, testing and demonstrating the deep disposal technology. Important tests planned at the laboratory during the coming three-year period are boring of a number of deposition holes, tests of the deposition sequence and retrieval, and trials with backfilling and sealing of tunnels. De-velopment and design of machinery and vehicles is planned in parallel with these trials. The goal is to be able to demonstrate the deposition technology in its entirety within a six-year period.

5.3.3 Safety assessment

The work of developing the safety assessment has been going on continuously since 1979 when the first safety report was presented (KBS-1). The most recent major assessment (SKB-91) was presented in 1991. SKB is currently carrying out a new safety assessment called SR 97, which will be presented in 1999. It will contain a number of new features compared with previous assessments, of which the most important are:

Safety assessment 1999 with partially new methodology

- A systematic documentation and treatment of important processes that can affect the repository in the long term and a new form for systematic description of the entire system of processes.
- A systematic treatment of deficiencies in numerical data for all processes that directly affect calculations of radionuclide transport.
- Studies of the course of events inside a canister with the assumption of defective copper shell.
- Three models for water flow and radionuclide transport in the bedrock are being compared for conditions at the Äspö HRL.
- A new method for determining the effects of earthquakes on the repository.

5.3.4 Research

SKB has been conducting extensive research since the end of the 1970s. The main purpose has been to develop the methods and gather the scientific data needed to assess the long-term safety of the repository. This research has laid the foundation for proceeding with the first stage of a deep repository. This does not mean that the research is over. Continued research can further improve the knowledge base.

The research programme has several goals. The most important is to provide as good a body of material for the safety assessment as possible. The research should also provide material for judging the development of alternative methods. Important topics for continued research include the following:

- *Spent fuel*. The durability of the spent fuel in groundwater was something SKB started investigating in 1977 (KBS project) and the present-day programme was adopted in 1982. Improved knowledge and models are being developed for the safety assessment.
- *Buffer and backfill*. The properties of the bentonite as a buffer between canister and rock are being investigated and an important research area is the stability of the bentonite (chemical and physical).
- *Structural geology and mechanical stability of the rock*. The rock is an important barrier that is supposed to protect the canister. Prior to siting, SKB is improving knowledge of margins in the rock's capacity to isolate the waste. Methods for surveying and interpretation of the structure of the rock are being further refined and more studies are being conducted regarding how earthquakes can affect a deep repository.
- *Water flow and transport*. Solute transport in the rock is dependent on factors such as groundwater flow and flow paths. Measuring the hydraulic properties of the rock in the area where the repository is to be situated and describing them with flow models is important for the safety assessment. Models and measurement methods are being progressively improved. It is also important to study how substances are retained in the rock by sorption on the minerals in the rock. Such experiments are being performed at the Äspö laboratory.
- *Groundwater chemistry*. Deep groundwater is an important part of the chemical environment in the repository. Investigations are being conducted to deter-

Buffer

Material between canister and rock

Bentonite

Clay, usually of volcanic origin

Sorption

Uptake of solutes on solid surfaces

mine how stable this environment is, how it reacts to the construction of the repository, and hot it might change in the future.

- *Radionuclide chemistry*. The chemical properties of radionuclides determine how mobile they are in buffer and rock. The influence of microbes, colloids, gas and pore water in concrete is being investigated.
- *Radioactive substances in the biosphere*. If radionuclides from a repository reach the ground surface, they can be spread in the biosphere. Models and data for calculations of the consequences of a release are being improved.

Mikrobes

Tiny organisms, e.g. bacteria and virus

Colloids

Particles that are so small they don't sediment

Concrete pore water

The free water in the concrete

Natural analogues

Examples from nature of materials and processes that have counterparts in the repository

SKB is participating in several EU projects. Two of them aim at learning from natural analogues of deep disposal. One concerns the natural reactors in Oklo, Gabon, and the other involves a uranium ore in Palmottu in southern Finland. The traces of the hydrogeological conditions that previously prevailed in Sweden and other countries are being investigated in two other EU projects. This gives an idea of what variations in water flows may occur and what an ice age may entail.

At Laxemar in Oskarshamn, SKB has drilled a hole for sampling and measurement in the rock down to a depth of 1,700 metres. This has increased knowledge of the rock and the groundwater at great depths.

Long-lived LILW will also be disposed of in the deep repository. SKB is conducting a project where such waste is being inventoried, the design of the repository developed and long-term safety assessed.

SKB is also conducting research on alternatives to the deep disposal method. We believe that transmutation is a particularly interesting alternative; it is the only known method which could significantly affect the content of radionuclides in the nuclear waste. There is considerable international agreement among nuclear organizations and experts that a successful development of transmutation will not eliminate the need for a deep repository. It can, however, alter the design premises for the deep repository and greatly reduce the quantity of long-lived radionuclides that have to be disposed of. It can affect the size of the deep repository and the design of the engineered barriers. The goals of SKB's research into the transmutation of long-lived radionuclides are as follows:

- Examine how the method can affect waste quantities and nuclide content.
- Determine if, how and when the method can be utilized to simplify, improve or develop the system for final disposal of nuclear fuel waste from the Swedish NPPs.

We also consider it our function to participate in an appropriate fashion in international projects – especially EU projects – in this field.

5.4 Environmental impact assessments and statements

Extensive work is under way to compile environmental impact statements (EISs) to accompany applications for siting permits for the deep repository and the encapsulation plant. The first time when an EIS is formally required is when SKB applies for a siting permit for the encapsulation plant. A similar document is required for the deep repository a few years later.

It is important to discuss what an EIS is to contain at an early point. To contribute to this discussion, a first draft of a table of contents for an EIS for the deep repository is appended to this programme.

The EIA process will continue throughout the entire coming six-year period. The EIA work can be expected to develop and deepen both on the national level and on the regional and local level. On the national level, the work has begun and the parties have agreed on a basic structure for work forms and content. Work on the regional level has been going on for a few years and is expected to continue under current forms. On the local level, both SKB and the municipalities in which feasibility studies are being conducted have intensive information activities and various forms for consultation and discussion have been developed.

EIA consultations

- national level
- regional level
- local level

When it comes to consultation on the concrete form and content of the future EIS, we expect that viewpoints from reviewing bodies on RD&D-Programme 98 and on the table of contents in the appendix will be brought up for discussion in a national EIA forum and in EIA consultations at the regional and local level. SKB plans to compile these viewpoints. One of SKI's tasks is to prescribe what is to be included in the EISs.

Prior to the site investigations, we plan to formulate a plan for the continued EIA work. The plan will be drawn up in consultation with the municipality and local and regional stakeholders. It will therefore underlie decisions on siting and construction of the encapsulation plant and the first stage of the deep repository.

5.5 Resources

5.5.1 Work forms

Research is conducted by universities, institutes of technology, etc. SKB conducts central portions of the safety assessments

SKB's own personnel force for execution of the programme is relatively limited. It is primarily concentrated to resources for management, planning and follow-up of the work. Beyond that, SKB conducts central portions of the assessments of the repository's long-term safety.

There is extensive international cooperation within the nuclear waste field

Research and development is conducted in cooperation with universities, institutes of technology, research institutes, consulting firms and individual experts in Sweden and abroad. Engineering and construction services are purchased from consulting and contracting companies. The same is true to a large extent of the operation of the existing facilities. A list of the institutions and companies participating in SKB's activities is published recurrently in our annual reports.

This international cooperation is important for maintaining a high level of competence and quality in the work. SKB has formal agreements on information exchange with organizations in Canada, Finland, France, Spain, Switzerland and the USA. Other forms of cooperation besides just information exchange are often included within the framework of the agreements. For example, ten foreign organizations from nine countries are participating in various projects at the Äspö HRL. Most of the natural analogue research is also being conducted in broad international collaboration.

SKB is also participating in various ways in a number of EU projects. Representatives from SKB participate in committees and working groups in the nuclear waste field within the EU, the IAEA and the OECD/NEA. Finally, the international assignments undertaken by SKB contribute towards maintaining and developing knowledge and contacts.

5.5.2 Organization

During the first half of 1998, SKB's organization has been revised to suit our goals and to enable this programme to be implemented. SKB is now organized into four departments:

- ***Siting*** – whose main task is to conduct feasibility studies and compile all the material that is needed to choose at least two sites for site investigations. This includes conducting EIA consultations and preparing EIS's, as well as building up the knowledge and the public trust that is needed to proceed with siting of the deep repository.
- ***Safety and Technology*** – whose main task is to develop and demonstrate safe and appropriate technology for interim storage, encapsulation, transport and deep disposal of spent nuclear fuel and long-lived LILW. Technical/scientific and safety-assessment competence have been gathered here to obtain an efficient translation of theoretical knowledge from scientific studies and experiments to practical application in site investigations, barrier design and construction of facilities.
- ***Operations*** – whose main task is to operate and maintain existing facilities and transportation systems in a safety, environmentally appropriate and efficient manner.
- ***Nuclear Waste Management*** – whose main task is to conduct qualified international consulting activities within the field of nuclear waste management. Improving the management of radioactive waste in Russia and the rest of Eastern Europe is an important part of these activities.

In addition there are staff functions for administration, accounting and financial control, quality/control and communications technology.

5.5.3 Costs

PLAN report

SKB's annual report of the costs of the nuclear waste programme

The costs of implementing SKB's programme are reported each year in a PLAN report. A rough estimation of the costs for the coming six-year period is given in Table 5-1. Priorities and scope may, however, change when new results emerge. It is therefore difficult to make detailed estimates for individual areas and for a longer period.

Table 5-1. Preliminary estimate of the costs for the coming six-year period (MSEK)

	1999	2000	2001	2002-2004
Siting				
General siting studies, feasibility studies, etc.	70	60	60	-
Site investigations	-	-	-	300
Research and safety assessment	55	60	55	160
Technology				
Encapsulation technology	50	55	50	150
Deep disposal technology	180	175	160	400

6 Siting

During the coming three-year period SKB plans to gather the remaining data needed to proceed with the siting of the deep repository. The next step involves concrete investigations with boreholes, so-called site investigations, on at least two sites. Viewed in a national perspective, the sites chosen for site investigations should possess good potential for a deep repository. The background data for this evaluation will mainly consist of general siting studies of more or less all counties in the country, results of feasibility studies and comparisons with other sites.

Before SKB begins the site investigations, we will present programmes on how they are to be carried out on each site and criteria for how the sites are to be evaluated. Furthermore, viewpoints on how areas are selected will be discussed in EIA consultations.

6.1 Overview

The siting process for a deep repository for spent nuclear fuel encompasses three steps: general siting studies, feasibility studies and site investigations.

General siting studies are initiated and conducted by SKB to ascertain the suitability of different regions for a deep repository. Feasibility studies (5–10) provide an overview on a municipal scale and include, among other things, investigations of what is known about the bedrock, how the municipality plans its land use, and environmental aspects. Analyses of economic and social aspects are also performed. The feasibility study determines whether areas may exist in the municipality that are of interest for further studies. In site investigations (at least two), a more detailed technical investigation of the bedrock is made. This step involves physical activities in the form of drilling and field studies lasting several years.

General siting studies
Feasibility studies
Site investigations
↓
Decision on where the deep repository will be sited
↓
Detailed characterization and construction
Initial operation
Regular operation
Closure

It is not until after site investigations and prior to detailed characterization on the main candidate site that the big decision on siting of the deep repository is made. All work prior to this decision (general siting studies, feasibility studies, site investigations) is supposed to contribute towards the preparation of a thorough environmental impact statement (EIS). Besides describing the environmental consequences of a deep repository on the selected site, an EIS is also supposed to describe alternatives for siting and alternative methods for disposing of the nuclear fuel waste.

An important difference between a deep repository and other underground rock facilities is that the properties of the rock must be explored in detail as they pertain to long-term safety. In this respect, SKB's investigations of the bedrock at several sites in Sweden has yielded new knowledge. Our conclusion from general experience and our own specific investigations is that Swedish crystalline rock offers good prospects for finding areas with suitable properties for isolating the radioactive material.

EIA
Environmental Impact Assessment

EIS
Environmental Impact Statement

Other important prerequisites for a siting is that the requirements of the Natural Resources Act's resource management provisions, municipal plans and other land use interests are met. The council in the concerned municipality must also have said yes to the siting.

6.1.1 Review and commentary of RD&D-Programme 95

SKI

Statens kärnkraft-inspektion (Swedish Nuclear Power Inspectorate)

KASAM

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

Many of the reviewers of SKB's RD&D-Programme 95 commented on the siting work. An exhaustive summary of all viewpoints is provided in SKI's evaluation report /6-1/. KASAM also published a special statement of comment /6-2/. Three different basic attitudes can be distinguished:

- The reviewing body accepts SKB's working method, but underlines the importance of broad background documentation for future decisions. In several cases, the reviewing body also calls for a clarification of the decision process, for example how the choice of areas for site investigations is to be made, or how the Natural Resources Act's so-called veto valve is to be interpreted and applied in different phases of the decision-making process.
- The reviewing body wants the site selection to follow a strictly scientific and systematic approach leading step-by-step to the best (safest), or at least the best possible, site. The attitude of the municipalities should not be the determinant factor.
- The reviewing body does not believe that SKB should conduct any siting work at all out in the municipalities. Instead, a free-standing method selection should be made and/or additional research should be performed. Some reviewing bodies want a special commission or authority to take responsibility for siting.

Those who believe another systematics is needed for the site selection process imagine that the best site can be identified by screening on increasingly detailed scales. No consideration should be given to public opinion, at least not in the initial stages; instead, bedrock conditions should determine the choice of site.

Measurements in boreholes are required to assess safety

We believe that such a process has poor prospects of success. The reason is that site-specific knowledge of the most important safety-related factors (groundwater flow, groundwater chemistry, conditions for radionuclide transport and rock mechanical conditions) is lacking on most sites. Generalized appraisals can be made, but only when boreholes and borehole measurements are available does it become possible to evaluate safety and compare areas from this aspect. It is furthermore highly uncertain whether municipal residents would accept a "best" site that has been identified in a centralized process without local participation. Foreign experience supports this view.

SKB believes that the best site is one which meets the safety and environmental requirements and where the deep repository is accepted.

6.1.2 Government decisions regarding the siting process

May 1995

In May 1995, the Government made a decision on SKB's supplement to RD&D-Programme 92 /6-3/. The decision contained a number of clarifications that have a vital bearing on the continued siting work. The most important points can be summarized as follows:

- The factors and criteria which SKB has designated as guiding principles for siting "should, in the opinion of the Government, serve as a point of departure for the continued siting work". The guidelines for the siting process are thereby set.
- An application for a permit to commence a detailed characterization should, according to the Government, be considered under both the Natural Resources Act and the Nuclear Activities Act. Previous programmes stipulated that this licensing procedure was to be based on the Natural Resources Act, to be supplemented by consideration under the Nuclear Activities Act after a detailed characterization had been performed. The new decision thus gives added weight to the review phase after the site investigations.

- The EIA process is said to be "an important instrument in contacts with authorities, concerned municipalities and the public". It is further said that "The Government assumes that the county administrative board in the county affected by feasibility studies, site investigations or detailed characterization will assume coordinating responsibility for the contacts with municipal and national authorities that are needed for SKB to assemble material for an EIA."
- "The municipalities affected by the site selection process should be given an opportunity to closely follow SKB's site selection studies". Municipalities in which SKB conducts feasibility studies can therefore on request receive up to two million kronor per year for "costs that enable the municipality to follow and judge and to furnish information in questions pertaining to final disposal of spent nuclear fuel and nuclear waste". The Government instructs SKI to administer this, and specifies that the money is to be taken from the funds set aside for financing of the nuclear waste programme.

December 1996

The review and commentary of RD&D-Programme 95 was followed by a Government decision in December 1996. Regarding the siting of the deep repository, the Government concludes the following /6-4/:

- A safety assessment of the repository's long-term safety should be completed before an application for a permit to construct an encapsulation plant is submitted, likewise before site investigations on two or more sites are commenced.
- Before the site selection process can progress into site investigations, concerned municipalities should have access to SKB's integrated account of general siting studies, feasibility studies and whatever other background material and comparison material SKB may wish to present. SKB should stipulate criteria for evaluation of the sites, and the factors which preclude further studies on a site, as well as the consequences of locating near the coast or inland and the consequences of locating in southern versus northern Sweden.
- SKB should consult with SKI and SSI on the conditions that should be applied to the site investigations.

Safety assessment finished before site investigations and application for permit for encapsulation plant

SSI

Statens stålskydds-institut (The National Institute of Radiation Protection)

6.1.3 National coordination

In May 1996, the Government appointed a national coordinator in the nuclear waste field. The coordinator is supposed to coordinate the information and research activities deemed necessary by concerned municipalities. He should propose forms for information exchange concerning management and disposal of spent nuclear fuel and otherwise be prepared to coordinate contacts between the municipalities and county administrative boards that are affected by the studies. The coordinator also has a central role in the EIA consultation at the national level.

6.1.4 Public opinion

SKB considers it inappropriate to locate a deep repository in a municipality where the local residents are opposed to such an activity. It is the municipal residents who are most affected by the advantages and disadvantages entailed by a deep repository. It is also among the municipal residents that personnel will primarily be recruited. The entire siting process must therefore be adapted to these basic prerequisites. The fact that the spent nuclear fuel can be temporarily stored in CLAB for many years gives us ample time to carry out siting in co-operation with the concerned municipalities.

CLAB

Central Interim Storage Facility for Spent Nuclear Fuel

6.2 EIS document and EIA consultations

According to Swedish legislation, an environmental impact statement (EIS) should accompany an application for a permit for activities that have an impact on the environment. The EIS is in turn the result of an environmental impact assessment (EIA) process. The EIA process is a support for planning and a means of obtaining good knowledge of the project's environmental aspects before a decision is taken.

6.2.1 EIS document

According to the Nuclear Activities Act, the Radiation Protection Act and the Environmental Code that enters into force on 1 January 1999, SKB must append environmental impact statements to its application for a permit to build and a licence to operate the deep repository and the encapsulation plant. An appendix to RD&D-Programme 98 contains the first draft of a table of contents for an EIS for the deep repository. The purpose is to initiate a discussion concerning what such a document should contain, both among concerned parties within the EIA process and among other stakeholders.

An EIS is formally required the first time SKB applies for a siting permit for the encapsulation plant. A similar document is required for the deep repository a few years later.

The Environmental Code generally describes what the EIS should contain. SKI has announced that they intend to specify the content with a view towards the coming facilities which SKB intends to erect. The Environmental Code stipulates that an EIS must contain:

- a description of the activity with information on siting, design and scope,
- a description of planned measures to avoid, reduce and, if possible, remedy significant harmful effects,
- the data required to ascertain and assess the principal impacts on human health, the environment and management of land and water which the activity can be assumed to entail,
- a presentation of alternative sites and alternative designs, along with an explanation as to why a given alternative has been chosen, plus a description of the consequences if the activity is not realized,
- a non-technical summary of the above information.

SKI intends to stipulate what the EIS must contain

EIS needed for
- siting of encapsulation plant
- siting of deep repository

SKI has announced that they intend to stipulate the required contents with a view towards the future facilities which SKB intends to build. The EIS for the deep repository and the encapsulation plant shall deal with both the facility itself and the final disposal system of which it is a part. The statement shall also give an account of how SKB has taken into account the viewpoints on safety and other matters that have been proffered by municipalities, environmental organizations, the public and others.

SKI and SSI are supposed to review the safety report and the EIS and submit a statement to the Government. Other expert authorities review other parts of the EIS. According to the Environmental Code, the entire application with appended EIS shall also be considered by the Environmental Court with public hearings.

What distinguishes the deep repository and the encapsulation plant from other industrial plants from an environmental point of view is mainly the question of short- and long-term radiological safety. Radiological environmental consequences of the facilities, and associated transport, will therefore be particularly described in the EIS. Safety assessments will comprise a central aspect of this work.

In the feasibility studies, SKB has made general assessments of the environmental impacts from various sources. Examples of such environmental impacts are noise and exhaust emissions from traffic to and from the facilities, rock heaps and disturbances of outdoor recreation, natural and cultural values. The consequences for the environment in most respects are small in comparison with other industries of equivalent size. One reason is that the activities do not involve any actual industrial process. Both the encapsulation plant and the deep repository are large construction projects, however, and there will be important local environmental issues to deal with, for example around the construction of access tunnels and deposition tunnels in a deep repository. The environmental consequences will be assessed when specific sites have been designated, i.e. in conjunction with the site investigations. Consequences in society of an establishment are more difficult to describe objectively. Here it is often a matter of different points of view. For example, opinions differ widely on a deep repository's effects on tourism or how a deep repository may affect an area's public image.

A deep repository probably has less of an impact on the environment than other industries of equivalent size.

6.2.2 EIA consultations at different levels

A deep repository is a controversial facility. Its design and siting engage many groups with disparate interests and values. To provide an opportunity for a broad discussion, SKB participates in EIA consultations on the national, regional and local level with the support of the EIA forums that have been established in recent years. Participants and what is dealt with in the EIA consultations at different levels are shown in Table 6-1. The table shows who the constant participants are, but other stakeholders are also called as needed. The work with local EIA consultations will be expanded to include e.g. nearby residents when the sites that are the main candidates for the deep repository are known. A brief description is given of what is discussed in each EIA forum. Naturally, all issues considered important can be brought up for discussion.

Table 6-1. Overview of EIA consultations

	Participants	Frequency of meetings	What is discussed
National EIA consultations	National coordinator (chairman), concerned feasibility study municipalities and county administrative boards, SKB, SKI, SSI, KASAM, Swedish Environmental Protection Agency, National Board of Housing, Building and Planning and Swedish Association of Local Authorities	2-3 times per year	General issues, e.g. choice of method for deep disposal, site selection procedure, and contents of the EIS.
Regional EIA consultations (example from Uppsala County)	County administrative board (chairman), municipality, SKB, SKI, SSI, KASAM, neighbouring municipalities (incl. Åland), national coordinator, military authorities, National Maritime Administration, NUTEK	2-3 times per year	What is to be included in, and the results of, the feasibility study. Information to the public. Viewpoints from neighbouring municipalities
Local EIA consultations	In connection with a feasibility study, the municipality and each provide information and solicit viewpoints.	Continuous public information work	Public information and knowledge accumulation. Examination of feasibility reports. Viewpoints on what is to be included in the feasibility study and a later EIS.

6.2.3 National EIA consultation group

A "National EIA forum in the nuclear waste field" was established in 1997. Participants are all concerned municipalities and county administrative boards, public authorities and SKB. The national coordinator is the chairman and responsible for the secretariat.

The main purpose of the national consultation group is to arrive at a consensus on what questions should be examined in the EIA work and how the EIA work should be conducted. Questions of a general importance for the contents of an environmental impact statement are also dealt with, along with general matters such as alternative system solutions (encapsulation-transport-deep disposal), alternative disposal methods and the contents of the siting documents.

Preparation groups can be appointed for analysis of different issues before they are brought up for more thorough treatment in the consultation group. Public hearings can be held if needed.

6.2.4 Regional EIA consultation groups

Local safety committee

Committee for public insight and information exchange in municipality with nuclear power plant. The members are appointed by the Government

In RD&D-Programme 92, SKB proposed that the siting of the encapsulation plant should be at CLAB in Oskarshamn. During the review of the programme, attention was drawn to the question of how an EIA process could be initiated for an encapsulation plant and a deep repository. A number of reviewing bodies commented on this matter and called for an initiative to create a forum for discussions of EIA issues. Inter-agency cooperation was initiated between SKI, SSI, the Swedish Environmental Protection Agency, the National Board of Housing, Building and Planning and the Central Board of National Antiquities, with KASAM participating as an observer. Furthermore, the local safety committee in Oskarshamn started an EIA process for the encapsulation plant. The safety committee also proposed that a working group should be formed under the leadership of the county administrative board in Kalmar County.

The "EIA forum in Kalmar County for CLAB and the encapsulation plant" worked during 1994–1997. The discussions in the EIA forum in Kalmar led in December 1995 to the report "Project encapsulation. Planning report for environmental impact assessment EIA" /6-5/. The authors of the report are participants in the group from the county administrative board in Kalmar County, Oskarshamn Municipality, SKI, SSI and SKB.

The mode of working in the EIA forum in Kalmar County for CLAB and the encapsulation plant yielded good results and was considered constructive by all parties. The participants thought that the work form offered good opportunities for dialogue and insight into the project and that important questions from the different actors could be picked up and examined early.

As far as feasibility studies for a deep repository are concerned, the Government decision from 1995 /6-4/ gives the county administrative boards a coordinating responsibility for the contacts with municipal and national authorities that are needed for SKB to gather material for an EIS. All county administrative boards where SKB is currently conducting feasibility studies (Kalmar County, Uppsala County and Södermanland County) have therefore started regional EIA consultation groups where the concerned municipality, neighbouring municipalities, national authorities and SKB are represented.

In Kalmar County the aforementioned EIA forum has been reconstituted to also work with questions pertaining to the feasibility study regarding the prospects of siting a deep repository in Oskarshamn Municipality. Altogether since the start in 1994, the EIA forum in Kalmar County has now met some two dozen times.

In Uppsala County the regional group for EIA consultations is called "Reference group for information exchange concerning the ongoing feasibility study work in

Östhammar Municipality". Since 1996 the county administrative board has called neighbouring municipalities, public authorities and SKB to consultation meetings. The frequency of meetings is two to three times per year. A small working group has also been formed consisting of Östhammar Municipality, the county administrative board, SKI and SSI as well as SKB. This group prepares matters for discussion at the bigger meetings where neighbouring municipalities, military authorities, KASAM and others also participate. Results in the form of questions that have come up during the discussions and SKB's answers to these questions are presented in the preliminary final report from the feasibility study in Östhammar Municipality /6-6/.

An EIA consultation group was started in Södermanland County in 1996. The county administrative board has held a few meetings on the matter, but the activities of the group have been of a lower intensity than in other counties where feasibility studies are being conducted.

6.2.5 Local EIA consultation groups

The information offices that SKB has opened in Nyköping, Oskarshamn and Östhammar, as well as previously in the feasibility study municipalities Malå and Storuman, provide important local support in the EIA work. Exhibitions, visits by companies and various associations, study visits to SKB's facilities, participation in information meetings arranged by the municipality or organizations, and participation at trade fairs are some examples of the work done by SKB to give the residents of the feasibility study municipalities an opportunity to obtain more information on nuclear waste disposal.

Each municipality chooses its own form for information and consultation

The municipalities go to great lengths to give their inhabitants insight and knowledge regarding the work around the feasibility studies. They are given an opportunity to find out about the results of the investigations, to ask questions, to discuss and to give their opinions and advice. The municipalities have chosen various ways to organize this work.

In Nyköping, the municipal executive board has formed an "Information and preparation group" with participants from all political parties. Furthermore, the municipality has formed a "Civil servant group" that has furnished SKB's investigators with the necessary material and followed SKB's work. To give organizations and the public an opportunity to follow the work close up and discuss its progress, a "Reference group" has also been formed with some 25 or so participants from various associations in the municipality. Municipal representatives have held several information meetings in the municipality with participants from various organizations.

In Östhammar, the municipal executive board has formed a reference group with participants from all political parties on the municipal council. Representatives of Tierp Municipality and the local nature conservation society are also invited to information meetings. During the feasibility study, the reference group has scrutinized the background reports. The group is conducting an independent scrutiny of the preliminary final report on behalf of the municipality and arranges information meetings for the public.

In Oskarshamn, the municipality has built up an extensive organization for educating its own politicians and encouraging debate and dialogue with the public. Six different working groups with at least five persons in each, including three politicians from the council, have been formed. The working groups also include representatives from neighbouring municipalities, associations, the church, trade unions and one representative from the local nature conservation society. A large number of information meetings have been held all over the municipality.

6.3 General siting studies and feasibility studies

Table 6-2 provides an overview of the siting studies thus far conducted by SKB and published in various reports, as well as what we are planning for the next few years. At present, supplementary county-specific general siting studies are being conducted. They will cover more or less the entire country. Furthermore, SKB intends to thoroughly explore the possibility of undertaking further feasibility studies.

6.3.1 County-specific general siting studies

In 1995, SKB conducted a general siting study on a national scale of siting prospects for a deep repository /6-7/. At present we are supplementing this material with county-specific general siting studies. The results from ten counties will by published during 1998 /6-8 – 6-17/. The county-specific general siting studies will cover more or less the entire country, except for Gotland County. The reason why Gotland is not being considered is that crystalline bedrock does not exist at the depth being considered for a deep repository.

The purpose of the county-specific general siting studies is to:

- determine roughly where potentially suitable versus unsuitable areas may exist within each county. The results will be used to identify municipalities that are suitable for feasibility studies,
- gather material that can be used as a basis for comparison in the selection of areas for site investigations,
- gather material to place investigated areas in their regional context.

The reason counties have been chosen as the geographic unit of study is that geological survey maps, as well as maps showing land use, are primarily broken down by county. Furthermore, the county administrative boards are prime assets both as discussion partners and as sources of planning information.

Long-term safety is the most important issue in the county-specific general siting studies. This in turn entails a focusing on the bedrock. It is SGU that carries out these investigations and makes an overall evaluation of which areas in each county are of interest from a geological point of view. Besides geological conditions, the county-specific studies also include general surveys of nature and culture protection areas, industrial areas, roads, railways and harbours. Land use interests will be reported separately from the geological surveys during 1998–99.

SGU
Geological Survey of Sweden

Potentially suitable areas found in feasibility studies are smaller and more well-defined than the larger, more generalized areas yielded by the geological county general siting studies. More detailed investigations may therefore reveal unfavourable conditions in parts of the areas judged to be suitable in the county general siting studies. For the same reasons, detailed investigations may identify favourable conditions in certain areas of those parts of the county judged as unsuitable in the general siting study. The conclusion drawn by SGU is that both general siting studies and feasibility studies are needed to obtain a comprehensive picture of the geoscientific conditions.

To determine whether an area may be of interest for further studies, SGU has applied the following geoscientific criteria in the county-specific general siting studies:

Rock types

In order for a rock type to be suitable for a deep repository, it should be present in large volumes. It should not contain ore or otherwise be unusual. It should be suitable for tunnelling. A homogeneous bedrock permits more reliable forecasts

Table 6-2. Overview of completed and planned siting and feasibility studies

Study	Commentary
Investigations of study sites (1975-1985)	More or less comprehensive site investigations with deep drilling and measurement of rock properties on some ten or so sites all over Sweden. Shows that sites with good geological potential can be found at various places in the country. Extensive documentation in technical reports. The results are included in the background material and the comparison material for selection of areas for site investigations (see section 6.4.2).
Geoscientific background material (1977-1995)	Investigations of vital geoscientific topics concerning e.g. tectonics, structural geology, earthquakes, hydrochemistry, ice ages, rock stresses etc. Approximately 40 technical reports are included in the background material for site selection.
General Siting Study 95	Integrated account of siting factors and siting prospects on a national scale. Dismisses most of Skåne, the Caledonides, Öland and Gotland. Examines on a national scale factors with regard to safety (geology), technology, land and environment as well as society that are of importance for judging siting in different parts of the country. Comprises part of the basis for SKB's assessments of the interest of a feasibility study. Included in the background material for selection of areas for site investigations.
County-specific general siting studies	Analysis of siting prospects in all countries with the exception of Gotland. Focus on geoscientific conditions. Indicate areas with potentially suitable versus 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.
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. Included in the background material for selection of areas for site investigations.
Feasibility study for siting of a deep repository within Storuman Municipality	Analyzes the prospects in Storuman Municipality. Designates two areas of interest for site investigations and prioritizes one of these. Sheds light on possible consequences of a deep repository siting from a regional and local point of view. Describes possible impact on the environment. Included in the background material for selection of areas for site investigations.
Feasibility study for siting of a deep repository within Malå Municipality	Analyzes the prospects in Malå Municipality. Designates two areas interest for site investigations and prioritizes one of these. Sheds light on possible consequences of a deep repository siting from a regional and local point of view. Describes possible impact on the environment. Included in the background material for selection of areas for site investigations.
Feasibility study for siting of a deep repository within Nyköping Municipality	Analyzes the prospects in Nyköping Municipality, in particular near Studsvik. Designates areas of interest for site investigations. Sheds light on possible consequences of a deep repository siting from a regional and local point of rview. Describes possible impact on the environment. Included in the background material, comparison material and (possibly) the screening material for selection of areas for site investigations. Preliminary final report available.
Feasibility study for siting of a deep repository within Östhammar Municipality	Similar in outline to other feasibility studies. Preliminary final report available.
Feasibility study for siting of a deep repository within Oskarshamn Municipality	Similar in outline to other feasibility studies. Preliminary final report during 1999.
Feasibility study for siting of a deep repository within Tierp Municipality	Starts in 1998. Outline will be discussed with the municipality.
Feasibility study for siting of a deep repository within X, Y ... Municipality	We hope to carry out at least one more feasibility study.

of bedrock conditions between boreholes and facilitates calculations of thermal and mechanical effects of the repository, for example how heat from the repository spreads in the rock. In the general siting studies, certain volcanic rock types and greenstone have in many cases been deemed unsuitable, while gneiss and granite have been regarded in most cases as suitable.

Greenstone
Generic name for altered, usually dark green, quartz-poor rock types

Soils

Areas with thin soil layers and with a high proportion of exposed rock are generally superior from a siting viewpoint to areas with thick soil layers. The reason is that a thin soil layer facilitates mapping of rock types and deformation zones. Glaciofluvial deposits (such as eskers) are unsuitable since they are important as groundwater sources.

Deformation zones

Deformation zone
General term for zones of weakness in the bedrock where the bedrock on each side has moved in relation to the other side

Certain parts of the bedrock have been deformed in extensive zones. The deformation may have been plastic or brittle. In the general siting study, large deformation zones have been regarded as unsuitable, since they may conduct water or be planes of weakness where rock movements may be triggered. The zones may also be disadvantageous from a constructability point of view.

Long-term stability

Sweden is situated in a geologically stable area. Studies show that earthquakes with the magnitudes that have occurred in Sweden during recorded history will probably not affect a deep repository /6-18/. However, much more violent earthquakes occurred in conjunction with the retreat of the continental ice sheet about 10,000 years ago, which would probably have affected a repository in the vicinity of the earthquake.

Fault
Deformation zone where the movements have primarily taken place in a brittle state

There are parts of Sweden where earthquakes occur more frequently than at other places. The location of these areas is shown in the general siting studies. Furthermore, areas are designated where rock movements have occurred in conjunction with the most recent ice age (postglacial fault movements). Special attention will be given to the question of long-term stability in feasibility studies carried out in areas with increased earthquake frequency or postglacial rock movements.

Hydrogeology

Recipient
Body receiving groundwater discharge

If the water capacity of drilled wells is low, this indicates that the hydraulic conductivity of the rock at repository depth is also low, which is favourable from a repository viewpoint. Areas where there is a large recipient, such as the Baltic Sea, are also considered favourable.

Overall assessment

Based on an overall assessment, each county has been divided on geological grounds into areas of the following categories:

- suitable (for further siting studies),
- probably suitable,
- probably unsuitable,
- unsuitable.

In areas designated as probably suitable or probably unsuitable, there is a lack of both modern geological maps and airborne magnetic surveys. In these areas, the assessment must be based on old geological maps and is therefore less certain.

The composition of the bedrock, the ore potential and the occurrence of deformation zones have been the most important factors in the overall assessment. As is evident from the map in Figure 6-1, there are suitable and unsuitable areas in all the counties studied thus far. Large continuous areas of potentially suitable bedrock are found in central Norrland, the Lake Mälaren Valley, southeastern Småland and Blekinge. According to SGU it is not possible to rank the interesting areas on the basis of the material that is available today.

There are both s uitable and unsuitable areas in the counties studied to date

The available data does not permit a ranking of areas

In summary, SKB concludes that bedrock of interest for further siting studies is present in all counties studied. At the same time there are large areas that are presumably not suitable. We will use these findings to try to initiate more feasibility studies.

6.3.2 North-south/Coast-interior

Purpose and scope of the inquiry

SKB has conducted a special inquiry 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 /6-19/. This inquiry was undertaken in response to remarks in the Government's decision on RD&D-Programme 95 and viewpoints on General Siting Study 95 from the reviewing bodies.

The purpose of the inquiry has been to:

- examine factors that can comprise differences in siting prospects between a siting of the deep repository in southern Sweden and one in northern Sweden,
- examine factors that can comprise differences in siting prospects between a siting of the deep repository near the coast and one in the interior,
- shed light on these differences from a siting viewpoint.

An important aspect of the work has been to assess the importance of the general trends that emerge for certain siting factors along the "north-south/coast-interior scale" and how these trends should be taken into account in relation to the variations that are known by experience to occur on a local scale. It has not been possible to designate suitable areas for further siting studies, since this requires more detailed studies.

Assessment based on important siting factors

Long-term safety

In General Siting Study 95, the conclusion was that it is not possible, on the scale in question, to exclude or recommend any parts or areas of the country. The only exception is large areas that can be excluded because the bedrock differs radically from the crystalline rock environment that is needed (the Caledonides, Gotland and Öland, and parts of Skåne).

The Caledonides, Gotland, Öland and parts of Skåne have unsuitable bedrock

The comparisons that have been made from the "north-south" and "coast-interior" perspectives have not altered this conclusion. Nevertheless, certain statistical differences can be seen for many geological properties. An example is the degree of exposure, i.e. the proportion of outcrops. A high degree of exposure generally offers advantages in geological interpretations of the conditions at depth. In average terms, the degree of exposure is greater in southern than in northern Sweden. In southern Sweden, the degree of exposure is also higher near the coasts than in the interior. Weighing such differences into the assessment of the siting conditions would, however, scarcely be meaningful, since it is not broadly calculated average values that are important but local variations.

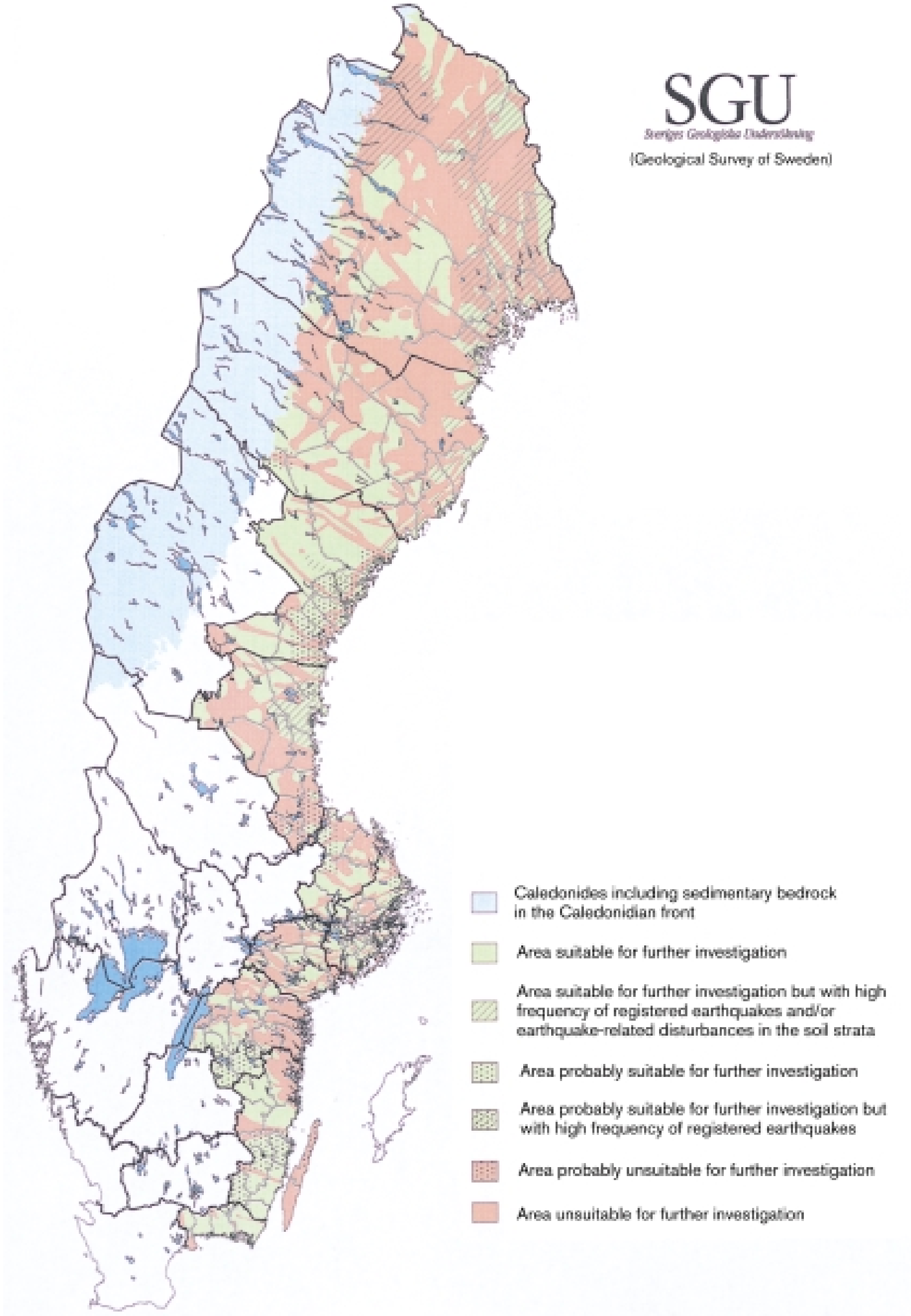


Figure 6-1. *The map shows a general assessment of siting potential with regard to geoscientific factors for the ten counties for which general siting studies are being published in 1998. Areas with an elevated frequency of earthquakes and rock movements since the most recent ice age have been specially marked.*

There are, however, differences that are general and "site-independent". The clearest such difference is the climate difference between north and south and the effects this can have on the bedrock. The picture of how the climate will change on a time scale of thousands and tens of thousands of years is not clear-cut. However, the forecasts point towards the northern parts of Sweden being ice-covered within a few thousand years, while this may take place tens of thousands of years later in the south. Similarly, deglaciation will take place later in the north than in the south.

Glaciation

Advance of glaciers or ice sheets

Deglaciation

Retreat of glaciers or ice sheets

Glaciation can have both positive and negative consequences from a safety point of view. On the one hand, a continental ice sheet can comprise an effective extra protective barrier that shields off the bedrock from the biosphere and virtually eliminates the risk of human intrusion in a repository. This argues in favour of siting the deep repository in northern Sweden, where glaciation comes earlier and lasts longer. On the other hand, both glaciation and, to an even greater extent, deglaciation cause extensive and potentially significant changes in the mechanical and hydraulic conditions in the bedrock. There is much to suggest, for example, that the postglacial fault movements that have been recorded at various places in Norrland are effects of rapid load changes in the bedrock that took place when the most recent ice cap retreated.

Both advantages and disadvantages with continental ice sheet

Climate variations and their effects can be viewed on a thousand- or ten-thousand-year timescale. The radiotoxicity of the radioactive waste declines considerably over such long spans of time. It can be roughly estimated that radiotoxicity decreases by a factor of 10 during the first thousand years after deposition and another factor of 10 during the subsequent ten thousand years /6-20/. This must be taken into account when factors related to climate changes are to be weighed into the assessments of the siting prospects. Furthermore, all fore-casts are of necessity less certain the longer the time horizon. This is particularly true of predictions concerning the biosphere, but to some extent also of what changes can be expected in the bedrock. For these reasons it can be asserted that greater importance must be accorded to reasonably calculable effects on a shorter time-scale than more hypothetical assumptions about changes over a very long time span. In this light, the advantages of early onset of permafrost followed by glaciation in the north is of greater importance than the possible negative effects that can occur when the ice melts many tens of thousands of years later.

The radiotoxicity of the waste declines with time while uncertainty increases

Hydraulic gradient

Pressure differences that drive the groundwater

A comparison of conditions on the coast and in the interior shows that important differences are mainly associated with the groundwater. The often lower hydraulic gradients at the coasts can be an advantage for near-coast locations. A disadvantage can be shorter flow paths (discharge conditions) from a repository on the coast compared with a repository in the interior. If recipient conditions are considered, a large receiving body of water, such as the sea, is an advantage. Other factors that have a bearing on the isolation of the waste and factors that lead to low dissolution and slow transport of released radionuclides in the rock are, however, more important.

Shoreline displacements

The combined result of postglacial uplift and changes in sea level

An adverse factor for coastal locations can be that ongoing and future changes in the chemical composition and flow of the groundwater entail difficulties in predicting long-term changes in the repository environment. These changes are ultimately dependent on climatic variations, above all shoreline displacements that follow in the traces of glaciation cycles. These phenomena can in the long term cause changes in flow patterns (discharge areas become recharge areas or vice versa) and radically alter recipient conditions, for example from marine environment to mainland. In a comparison, an inland siting can result in groundwater conditions that are substantially more stable over long time spans and thereby easier to predict.

Another important factor is the occurrence of saline groundwaters. Without going into the processes that are believed to control this phenomenon, we can observe that saline groundwaters become increasingly common closer to the

Brine
Water with a salinity of more than 10 percent

coast. Moderate salinities (in the order of five grams per litre) are common at repository depth in near-coast locations. The Äspö HRL outside Oskarshamn provides examples of this. At greater depths, for example at a depth of over 1,000 metres in a borehole on the Laxemar Peninsula a few kilometres west of Äspö, very saline groundwaters have been found (close to brine).

Salt water can have both favourable and unfavourable effects on a deep repository. Saline groundwater relatively close to the surface can be an indication of low groundwater circulation, which is an advantage. Another advantage is that future deep-drilled wells will be less likely in that part of the bedrock where saline groundwater occurs. A disadvantage is the negative effects salt water can have on the materials being discussed for backfilling of the deep repository's tunnels after deposition. This can be compensated for by changing the composition of the material, but this can in turn lead to technical complications and higher costs. Very high salinities should be avoided, since they can damage the function of the buffer of compacted bentonite that surrounds the canisters in the deep repository.

Technology

The obvious disadvantage of a siting in northern Sweden from a technical/economic viewpoint is the long transport distance from the planned encapsulation plant to the deep repository. In the same way, a siting in the interior is unfavourable from a transport viewpoint, since both sea and land transport are then required. The transport need will exist during the entire operating phase and include not only the waste, but also buffer material. The transport aspects can be evaluated fairly well on an approximate scale and have been studied in the feasibility studies that have been or are being conducted.

Both Swedish and international experience shows that radiological safety in conjunction with transportation to the deep repository will be able to be kept at a high level, regardless of transport distance and transport mode. On the other hand, the waste shipments, like all other heavy shipments, can entail both the usual accident risks and some environmental load.

Depending on the siting location, more or less extensive construction of transport ways (railway or roadway) may be required. This entails both environmental incursions and added costs, but can at the same time provide regional and local improvements of the infrastructure. A calculation example taken from the feasibility studies provides an idea of the cost aspect. Expressed in relative terms, a siting in the interior of Norrland (sea transport to nearest harbour, followed by approximately 150 km overland transport including considerable investments in transport ways) increases the costs of the deep repository project by roughly five percent compared with a siting on the east coast in southern Sweden (only short sea transport).

Shipments to a repository in the interior of Norrland raise the costs by about 5 percent

In can thus be concluded that transport is feasible from a safety and technical point of view and that the extra costs associated with a "distant" siting are relatively moderate. Perhaps the question of transport is more than anything a question of attitudes and public opinion. Shipments of radioactive materials are perceived by many people as dangerous, inappropriate or at least unnecessary. Whether this concern is well-founded or not, in a technical sense, it is a reality which must be recognized.

As far as the prospects for building and operating the deep repository's facilities are concerned, it is difficult to single out any factors which could in a general sense be of great importance from the north-south or coast-interior perspectives. Two factors can nevertheless be mentioned. One is the initial temperature in the bedrock, which decreases towards the north. The temperature affects the geometric configuration of the repository. Higher temperature necessitates wider spacing of the canisters, resulting in a larger repository. Calculations show that a repository in southern Sweden may require 15–20 percent more space than a repository in northern Sweden. This can raise the cost of the deep repository project by a couple of percent, but hardly has any other crucial consequences. The second factor is the previously mentioned occurrence of saline groundwaters in near-coast locations. Besides safety-related consequences, saline groundwater can increase the maintenance need during the operating period.

The lower temperature in Norrland makes the repository a couple of percent cheaper

Land and environment

Large land areas that are of national interest for nature conservation are found to a large extent in the Caledonides, around large lakes, along river valleys and in coastal and archipelago areas. The nature protection aspects can, depending upon protection value and other circumstances, restrict the siting options to a greater or lesser extent. For large parts of the country, the restrictions are much greater in the coastal region than in the interior.

Otherwise, demand for land for other purposes is closely tied to population density. The same applies to a great extent to various culture conservation interests, as well as recreational interests. This means that the siting prospects may be more favourable from these viewpoints in the northern than in the southern parts of the country, and that the interior may provide better prospects than coastal districts. It is, however, local circumstances – not overall average values – that are decisive.

As far as the impact of the deep repository project on the environment is concerned, it is difficult to see any general differences from the coast-interior and north-south perspectives, with the important exception of the environmental consequences of the transportation activities.

It is not possible to draw any general conclusions about where the best place is in Sweden. Rather, local conditions decide

Overall assessment

SKB's assessment is that we cannot, based on general comparisons and considerations on an broad scale, either recommend or exclude a near-coast siting, rela-tive to a siting in the interior. The same applies to comparative evaluations of siting prospects in the northern versus the southern part of the country. Assessments of suitability must instead be based on studies of concrete areas.

The best arguments for the correctness of the above conclusion are obtained from the feasibility studies that have been carried out. These show that it is possible, on the scale of the feasibility studies, to identify areas which, on overall assessment, are of interest for further siting studies, both in two municipalities in the interior of Norrland (Storuman and Malå) and in two municipalities along the east coast further south (Östhammar and Nyköping).

6.3.3 Feasibility studies

Feasibility studies have been carried out in Storuman and Malå and the results have been published. At present feasibility studies are in progress or planned in four municipalities: Nyköping, Östhammar, Oskarshamn and Tierp. A map with the different feasibility study municipalities is shown in Figure 6-2.

Storuman
Västerbotten County
Surface area
7,500 km^2
Population
about 7,000

Malå
Västerbotten County
Surface area
1,610 km^2
Population
about 4,000

Storuman

The results of the feasibility study in Storuman were published in February 1995 /6-21/. The feasibility study showed that there are two areas that may be suitable for a deep repository, one of which was prioritized. The existing infrastructure could be used for transportation to the deep repository.

In September 1995, the population of Storuman voted on whether SKB should be allowed to continue looking for a final disposal site in Storuman Municipality. Voter turnout was 73 percent. The result was that 28 percent voted yes and 71 percent voted no. The percentage of blank votes was one percent. SKB has since terminated all siting activities in Storuman.

Malå

The results of the feasibility study in Malå were published in March 1996 /6-22/. It showed that there are two areas in the municipality that may be suitable for a deep repository. However, infrastructure investments would be required for transportation. The municipality conducted an independent review of the feasibility study with the aid of an expert group. They found that the feasibility study answered all of the questions it raised.

A referendum was held in the municipality in September 1997. To the questions “Should the Swedish Nuclear Fuel and Waste Management Company be allowed to continue looking for a site for deep disposal of spent nuclear fuel in Malå Municipality?” 44 percent answered yes and 54 percent no. The percentage of blank votes was two percent and voter turnout was 87 percent. SKB’s activities in Malå have now ceased.

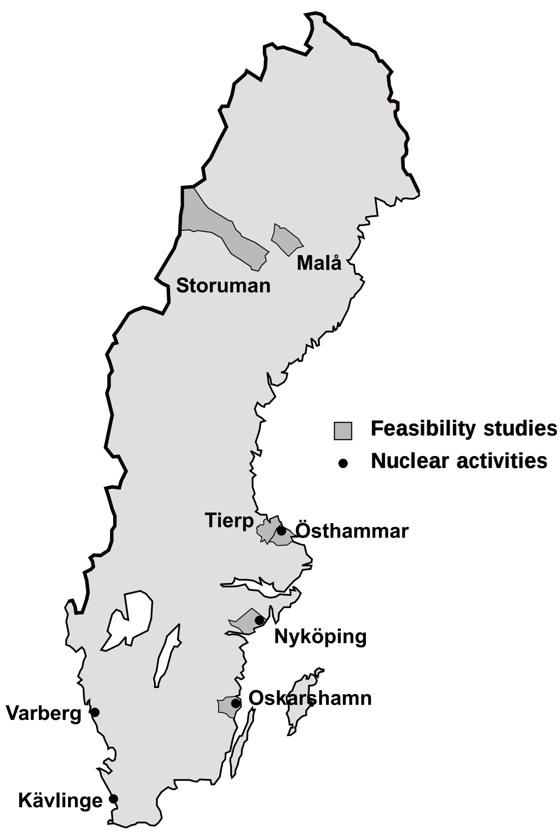


Figure 6-2. *Municipalities where SKB has conducted or is conducting feasibility studies.*

Experience from Storuman and Malå

SKB's and other's information activities in Storuman and Malå have been evaluated, see for example /6-23/. The basis for the evaluations has consisted of:

- interviews with municipal residents and local representatives of the municipality who have been involved on the yes or the no side,
- analysis of mass media coverage,
- viewpoints of SKB employees who have worked with the feasibility study and from concerned individuals at central agencies and local bodies.

The no side's most important argument against a repository was concern about the disposal method and the transport risks. Furthermore, they believed that tourism and reindeer herding would be negatively affected. Other common arguments were that there is a risk that the deep repository would receive nuclear waste from all of Europe and that the Government can override the municipal veto if the municipality says yes to a site investigation.

The yes side underscored the national responsibility and the opportunities for employment and development of the municipality. Another argument for a site investigation was that it would not be binding and the municipality could say no at a later stage of the siting process.

Both the yes and no sides and many others who participated in the discussion called for greater involvement on the part of the Government, the Riksdag (parliament) and regional bodies. A single municipality does not always have the resources to examine all sides of such a complex question as what the consequences of an establishment of a deep repository might be. This applies both to safety issues and the possible benefits of a deep repository for the municipality.

The investigations show that the need for information in the beginning of the siting process is great, since many municipal residents adopt a standpoint at an early stage. A general experience is also that the feasibility studies have stimulated interest in the nuclear waste issue in the municipality and the region in many ways. The regional media debate is stimulated, and researchers in the social sciences in particular take an interest in the subject /6-24, 6-25/. In /6-26/, social scientists from Umeå University report their studies of opinion formation prior to the referendum in Malå.

Nyköping

In May 1997, SKB published a preliminary final report on the feasibility study in Nyköping Municipality /6-27/. At present the municipality is reviewing this report. It may be decided that the material needs to be supplemented in some area or that new questions need to be answered. The final report is expected to be finished during 1999.

Nyköping
Södermanland County
Surface area
2,100 km²
Population
about 49,000

Via its working groups, the municipality has been kept continuously informed of the progress of the feasibility study. On occasions when interim results on specific aspects have been published, meetings have been held where those responsible for the studies have presented their results and conclusions to the municipality's information and preparation group and the reference group. The media have been informed in the same manner. In parallel with the investigation work, EIA consultations have been held at the county administrative board in Södermanland. Further, information has been furnished to the public on a number of occasions.

The infrastructure and nuclear competence available in Studsvik would prove valuable if the deep repository were to be sited in the municipality. The municipality is also particularly interested in having the possibilities of siting the repository near Studsvik explored.

Studsvik

Originally centre of nuclear research. Built in 1950s

Now about 600 people work at Studsvik, both in the Studsvik Group and in other companies

Studsvik is in the midst of sensitive archipelago surroundings, including the Stendörren Nature Reserve

Studsvik has a rock cavern for LILW. The waste comes from the research activities in Studsvik, but also from industry, research and hospitals. The repository was ommissioned in 1984

Three different siting cases have therefore been dealt with in the feasibility study:

- Both the surface facilities and the underground repository are located in Studsvik.
- The surface facilities are located in Studsvik while the underground repository is located some distance away (up to about 10 km). The two parts are connected by an inclined tunnel.
- Both surface facilities and the underground repository are sited within the municipality but at another place than Studsvik.

Siting at Studsvik

There are good possibilities for siting the deep repository's surface facilities at Studsvik. Two alternative locations within the existing industrial area have been identified. One alternative entails that several of the functions are placed in rock caverns built adjacent to an existing rock cavern. In the other alternative, all installations are built on the surface in the northern part of Studsvik.

In both cases the harbour in Studsvik can be utilized for sea transport of waste to the deep repository. Shipments of buffer and backfill material to the deep repository and rock spoils away from it can go on smaller vessels via Studsvik's harbour or by road and sea transport via Oxelösund's harbour.

It is unclear whether the bedrock beneath Studsvik satisfies the requirements for a deep underground repository. There are probably persistent fracture zones in the area, which would reduce the available repository volume. Furthermore, the area is partially covered by thick soil layers, impeding investigations. There are also uncertainties regarding what effects a meteorite impact in Tvären (a sea bay adjacent to Studsvik) has had on the bedrock. The factor in favour of Studsvik is good rock quality within the limited rock volume that can be observed in the existing rock cavern. Before the possibility of locating the underground repository at Studsvik is dismissed, further investigations should therefore be conducted. This requires deep drilling, which will only be done if a site investigation is undertaken in the municipality.

Siting within ten kilometres of Studsvik

Figure 6-3 indicates generally favourable areas with respect to bedrock and land use. As the map shows, there are three areas of interest near Studsvik. The largest area is situated west of Björksund, about ten kilometres west of Studsvik. The area has a large proportion of exposed rock and is dominated by homogeneous gneissic granite. The distances between persistent fracture zones are judged to be sufficient to accommodate a repository. The size of the area allows great flexibility in adapting the detailed configuration of the deep repository to local rock conditions.

The two other areas are situated a few kilometres northwest of Studsvik. They are smaller than the aforementioned area, providing less flexibility in the detailed configuration of the repository. The areas are still of interest, however, since they are situated close to Studsvik and therefore share its transport advantages.

All three areas can be reached by tunnel from Studsvik, which means that the surface facility can be situated there. Transportation of waste, backfill material and rock spoils can go through the tunnel, mitigating the impact on the environment. If the tunnel is long, a ventilation shaft may be needed along the access tunnel plus an additional shaft for ventilation, other utilities and personnel transport to a smaller installation above the deep repository.

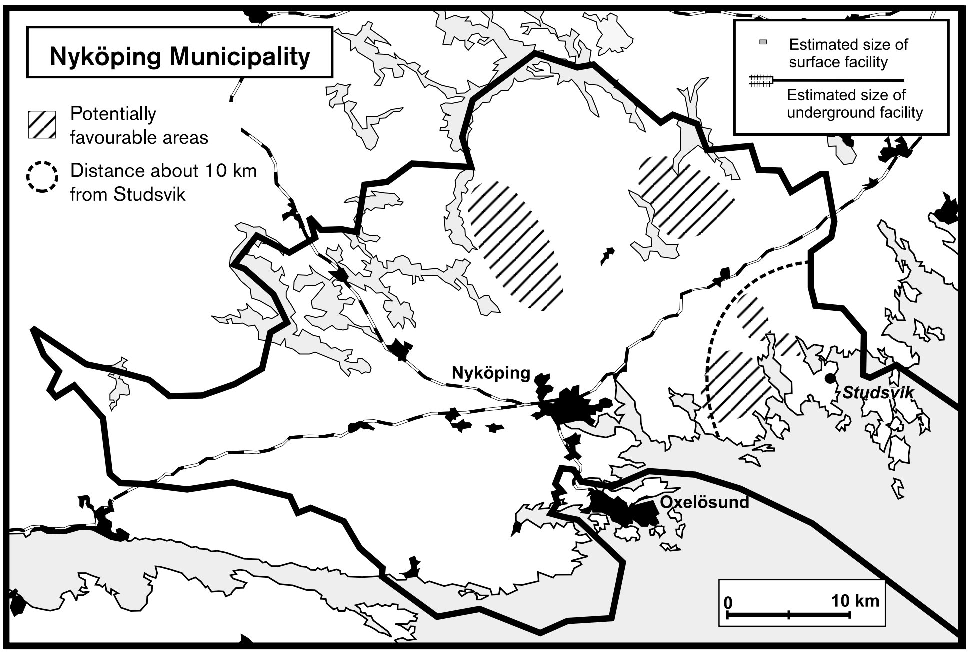


Figure 6-3. *Potentially favourable areas in Nyköping Municipality.*

Three interesting areas near Studsvik

Other parts of the municipality

There are two areas in the northern part of the municipality that are of interest with respect to bedrock conditions and land use considerations. One area is situated east of Lidsjön Lake and includes SKB's study site Fjällveden. The investigations from the 1980s show that the bedrock there is probably suitable for a deep repository. The other area of interest is located in the northeastern part of the municipality. If a deep repository were located in either of these areas, a new railway or new roads would be needed. The necessary construction works could entail incursions into sensitive natural and cultural environments.

New railway or road may entail incursions into sensitive natural and cultural environments

SKB's preliminary assessment

The areas that can be reached via a tunnel from Studsvik are the most interesting for a possible site investigation. Certain functions and the nuclear competence that is available in Studsvik can then be utilized for the deep repository as well.

Östhammar

Östhammar
Uppsala County
Surface area 2,790 km^2
Population about 22,000

The feasibility study in Östhammar Municipality was conducted in a similar manner to that in Nyköping. A preliminary final report /6-6/ was published in September 1997. The municipality is expected to be finished with its review of the report at the end of 1998. Supplementary studies may be needed both during and after the review. The final report is expected to be finished during 1999.

As in Nyköping Municipality, a comprehensive information programme has been carried out. As described earlier, an initial EIA consultation is also under way at the county administrative board in Uppsala County.

Like the Studsvik facility in Nyköping, the nuclear power plant in Forsmark offers advantages in terms of nuclear competence and infrastructure. This factor was given special consideration in the feasibility study.

There are three reactors with a combined capacity of 3,090 MW in Forsmark. The Forsmark Nuclear Power Station accounts for one-sixth of Sweden's electricity production. The plant has about 900 employees

The Forsmark Nuclear Power Station also handles operation of SFR

Siting at Forsmark

Preliminary results from the feasibility study show that the prospects for siting a deep repository at Forsmark are good. The surface installation can be located at two different places. One is situated northwest of the Forsmark Nuclear Power Station and one next to SFR's surface facility. Of these, the location at SFR is preferable. Figure 6-4 shows a possible layout of the deep repository's surface installation next to SFR's surface installation.

The underground portion can then be situated between SFR, the Forsmark plant and Bolundsfjärden Bay, see Figure 6-5. Existing data indicate that the bedrock there is homogeneous, with few deformation zones and without ore deposits. Disadvantages are that the area is relatively small, that it is partly covered with water and that there are certain geological uncertainties. This last-named problem requires deep drilling to clarify.

If the deep repository is built at Forsmark, most of the radioactive waste in Sweden will be deposited at one place. There will be no waste shipments on public roads or railway. Overland shipments of other materials will also be few. Security and other services can be coordinated with the Forsmark Nuclear Power Station, as long as it is in operation.

Siting within ten kilometres of Forsmark

In this alternative, the surface portion of the facility is located at SFR and the underground portion up to about ten kilometres from there. The two facilities are connected by a tunnel. If the tunnel is long, one ventilation shaft may be needed along the access tunnel and another shaft above the deep repository for ventilation, other utilities and personnel transport. In this case, the area south-east of the Forsmark Nuclear Power Station appears to be the most suitable, provided that the facility can be designed so that the special nature interests that exist in this area can be protected.

It is also possible to build the repository beneath the sea outside Forsmark. It is not, however, possible to make any judgements of the suitability of the marine area based on present-day material. This requires at the minimum supplementary airborne measurements and a geological survey of the nearby islands.

SFR

Final repository for radioactive operational waste

The repository has been in operation since 1988

Figure 6-4. *Example of layout of the deep repository's surface facilities next to SFR's surface facility.*

Other parts of the municipality

The geological investigations focus attention on nine areas of interest for further studies. Several of these are, however, unsuitable from the viewpoints of nature conservation and land use.

Figure 6-5 shows three areas in the southern part of the municipality where the bedrock is of interest for further studies and where official plans do not report any special land use interests. All three areas lie along the railway, which is an advantage from an environmental point of view.

SKB's preliminary assessment

Advantages in locating surface facility next to SFR

Based on what we know today, the area in Forsmark between SFR and Bolundsfjärden Bay is the most interesting for further studies, taking into consideration geological factors, land use interests, environmental impact and transport aspects.

The deep repository's surface facility can be situated adjacent to the existing SFR facility. The impact on the area's sensitive natural values can thereby be minimized. Certain functions of the Forsmark Nuclear Power Station and SFR can be co-utilized, and the repository can have access to the nuclear competence that exists there.

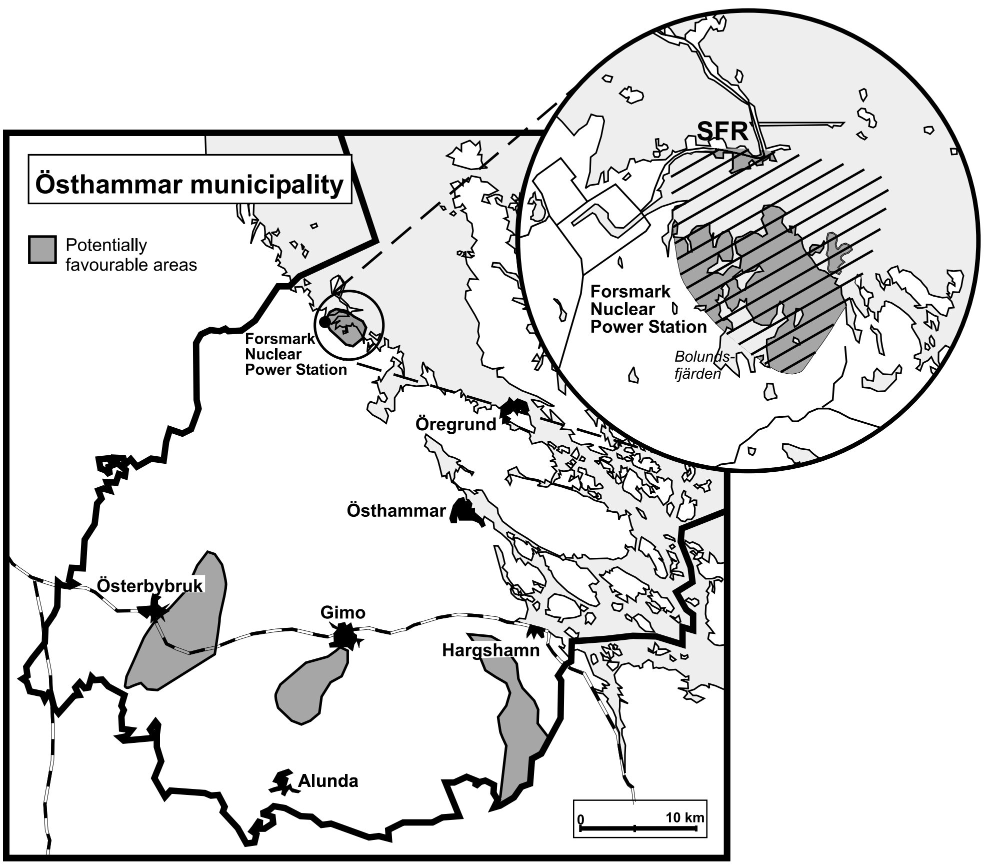


Figure 6-5. *Potentially favourable areas in Östhammar Municipality and locally at the Forsmark Nuclear Power Station.*

Oskarshamn
Kalmar County
Surface area
1,050 km²
Population
about 27,000

There are three reactors with a combined capacity of 2,272 MW on the Simpevarp Peninsula north of Oskarshamn. The first reactor was commissioned in 1972 and was Sweden's first reactor in commercial operation. OKG Aktiebolag has about 1,100 employees. OKG also handles the operation of CLAB, the Central Interim Storage Facility for Spent Nuclear Fuel

All feasibility studies must be completed before Oskarshamn takes a stand on a site investigation

Oskarshamn

In October 1996 the municipal council of Oskarshamn decided to participate in a feasibility study for the siting of a deep repository. The decision was preceded by preparatory activities in which both the municipality's politicians and officials and the general public were involved. Among other things, a broad information programme was carried out in which the young people in the municipality were deeply involved.

The decision stipulates the following conditions for the feasibility study /6-28/:

- The municipal council shall approve a detailed programme for the feasibility study, based on experience from feasibility studies in other municipalities, and set up an organization for the municipality's participation in the study.
- The municipal council shall comprise a reference group for the feasibility study and the environmental impact assessment (EIA) work.
- The decision-making process and the EIA procedure shall be coordinated nationally.
- The municipal executive board is responsible for day-to-day decisions in the feasibility study.
- Oskarshamn's neighbouring municipalities shall be kept informed, and after the feasibility study is concluded be given an opportunity to comment on the results of the feasibility study.
- If, on conclusion of the feasibility study, Oskarshamn Municipality declines further studies, this shall be respected.
- No decisions will be made in Oskarshamn concerning continued studies in the form of site investigations until:
  - all feasibility studies in the country have been concluded, reviewed and commented on by concerned authorities with respect to technical and scientific content,
  - there is a site investigation programme that has been reviewed and commented on by the authorities,
  - clear site selection criteria have been stipulated for choice of deep repository site,
  - the conditions under which the veto valve can be used in the voluntary siting process have been clarified.

In the spring of 1997, SKB produced a work programme for the feasibility study /6-29/. At the same time, Oskarshamn Municipality formed a feasibility study organization to follow the study for the purpose of becoming better informed on nuclear waste matters and conveying information to the residents of the municipality. The technical investigation work began in the summer of 1997. The studies and the information activities resemble those done in other feasibility studies. Ongoing work and results are reported as they become available.

Tierp
Uppsala County
Surface area
1,540 km²
Population
about 20,000

Tierp

The municipal executive board in Tierp Municipality was informed at the end of May 1998 of SKB's interest in conducting a feasibility study in the municipality. The reasons for this interest are firstly that the regional general siting study of Uppsala County shows that suitable bedrock may exist in the municipality, and secondly that a deep repository in the Forsmark region would affect both Östhammar and Tierp municipalities. On June 16 the municipal council in Tierp voted unanimously to participate in a feasibility study. At present a work programme for the feasibility study is being drawn up. The investigations are projected to start in the autumn of 1998 and a preliminary final report should be able to be completed by late 1999/early 2000. The feasibility study should be completed in 2000.

Remaining supporting documentation

The county studies will be completed during 1998 or early 1999, providing a good body of material for assessing the siting prospects in different parts of the country. The ongoing work of initiating new feasibility studies will be based on this material. As before, SKB will only conduct feasibility studies in municipalities that actively support them.

The feasibility studies in Nyköping, Östhammar and Oskarshamn can presumably be concluded during 1999. The feasibility study in Tierp and additional feasibility studies can derive benefit from the experience gained and the methodology that has now been thoroughly tried and proven. Provided that new feasibility studies can begin in 1998/99, SKB should be able to select at least two areas for site investigations during 2001.

6.3.4 Programme for future work

SKB's goal of selecting areas for site investigations during 2001 entails that a large body of material needs to be gathered and evaluated. We plan to conduct the work as two parallel projects: one for compilation of comparison and background material and one for gathering, structuring and evaluation of screening material (the feasibility studies). Compilations of comparison and background material will be published before the work of selecting areas for site investigations is begun.

As before, the siting work will be conducted openly and with continuous information on the progress of the work. Besides participating in information meetings and other forms of public debate, we will furnish information to the municipalities participating in the feasibility studies, the safety authorities and participants in EIA consultation groups at various levels. SKB's local offices in the feasibility study municipalities will furnish information to nearby residents and other interested inhabitants of the municipality and the region.

Viewed in a six-year perspective, we hope to have come a long way with the site investigations. The work of gathering the necessary supporting documentation for an application to site and build a deep repository on one of these sites will then also have been commenced.

6.4 Choice of areas for site investigations

The choice of at least two areas for site investigations is an important step in the siting process. It is not formally regulated in current legislation. However, the Government has, in its decision on RD&D-Programme 95, set up certain conditions (section 6.1.2). It is SKB's responsibility to carry out the screening process. SKI and several reviewing bodies have called for a clear account of how we plan to carry out this step in the siting process. The grounds on which we plan to base the choice are presented here. How the material can be structured and evaluated is further discussed. The procedure and criteria for the selection will be further discussed in EIA consultations and possibly modified.

6.4.1 Regulatory body opinions prior to site selection

Before site investigations, the authorities should give their view on disposal method and chosen sites

In SKB's view, site investigations can hardly begin before the regulatory authorities (SKI/SSI) give their opinion on the chosen disposal method and selected sites. Such regulatory body opinions have been called for in the national EIA consultation group, by for example representatives of municipalities in which feasibility studies are conducted.

Method

In conjunction with RD&D-Programme 98, we present alternative methods for disposing of the radioactive waste and we describe and explain the merits of the method which SKB believes has the greatest advantages (the system analysis). Before selection of sites takes place, we believe an opinion is needed from the regulatory authorities indicating whether SKB's account of this method is adequate to justify site investigations (regulatory body opinion on choice of method prior to site investigations).

Site

SKB will submit a broad body of siting data and a structured and reasoned choice of at least two sites. SKB will also submit a programme for site investigation with criteria for site evaluation. We believe that an opinion is needed from the authorities indicating whether SKB's account and reasons for choice of sites is adequate for proceeding with site investigations (regulatory body opinion on choice of site prior to site investigations).

6.4.2 Available and planned supporting material prior to site selection

A large body of material will be compiled and reported before areas for site investigations are selected. It will include background material, comparison material and screening material.

The background material is the general knowledge base on which different judgements and selections will be based. It includes e.g. general overviews or special investigations of geoscientific issues in particular. General Siting Study 95, as well as the county-specific reviews, are also included in the background material. The same applies to the more specialized siting studies, for example the special inquiry reported in section 6.3.2 concerning North-south/Coast-interior /6-19/.

Supporting material for choice of areas for site investigations
- Screening material
- Comparison material
- Background material

The comparison material consists of compilations of siting prospects in other areas, including the study sites where we have previously conducted investigations, and areas identified in regional general siting studies or in the municipalities that have declined further participation in the siting process. Information that has emerged from the Finnish site investigations can also be of interest, since it concerns the same type of bedrock.

The screening material consists of results of feasibility studies in the municipalities participating in the siting process. A large part of all this material is already available, see Figure 6-6. Table 6-3 contains an overview of this material. The existing material has already been described in brief in Table 6-2.

Table 6-3. Supporting material for choice of areas for site investigations

Completed investigations	Background material	Comparison material	Screening material
Study site investigations, 1979-85		X	
Special geoscientific studies, 1977-95	X		
Finnish site investigations		X	
General siting study 95	X		
General siting study, nuclear municipalities		X	
Inquiry "North-south/Coast-interior"	X		
County-specific general siting studies	X	X	
Feasibility studies		X	X

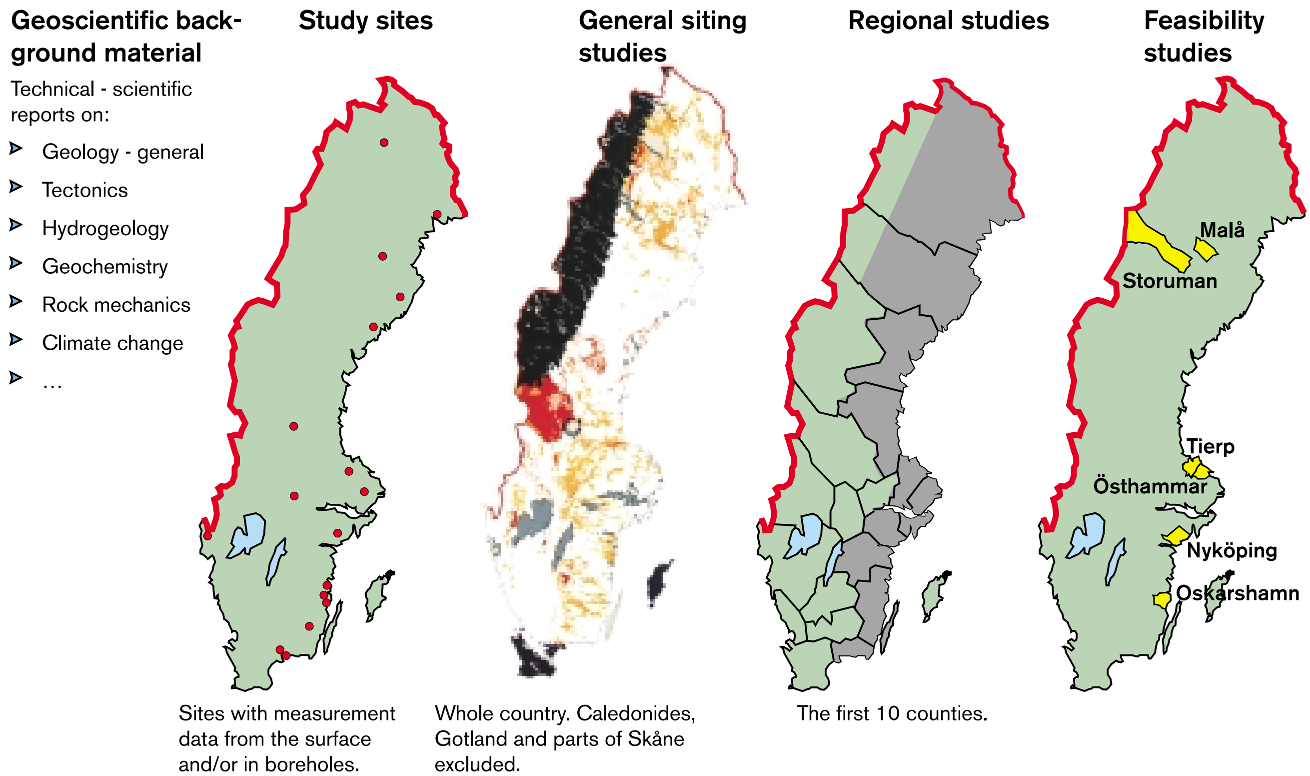


Figure 6-6. *Siting data on different scales.*

In addition to the siting data described above, SKB will present comprehensive material concerning the disposal method and the site investigations. This material includes a safety assessment, a site investigation programme, criteria for site evaluation and an integrated account of screening material with reasons for choice of areas. This combined material, which SKB will refer to in connection with the choice of areas for site investigations, will gradually be gathered over the next three years in the way shown in Table 6-4. In addition to the material described in the table, viewpoints will also be obtained from EIA consultations.

6.4.3 Screening procedure

The choice of areas for site investigations will be made in close consultation with public authorities, municipalities and other concerned parties within the framework of the EIA process. The screening is based on the aforementioned supporting material. In an overall assessment of available data, the selected areas will have good prospects of fulfilling the requirements on safety and environment protection that will be made on the siting of the deep repository. Furthermore, the sites must be located in municipalities that are willing to participate in the siting process.

It is important that the selection of areas for site investigations be wellgrounded and well-documented. The planned procedure is described below and consists of three steps: structuring of facts, evaluation of facts and choice of areas, see Figure 6-7.

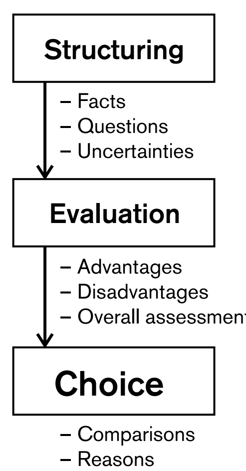


Figure 6-7.
Steps in site selection.

Table 6-4. Timetable and sequence for coming accounts

Year	SKB account	Review statements, statements of comment, Government decisions
1998	- RD&D-Programme 98 - Alternative methods - System account (KBS-3) incl. zero alternative - Progress report regarding criteria for site evaluation - Inquiry "North-south/Coast-interior" - 10 county-specific general siting studies	
1999	- 13 county-specific general siting studies (remaining county studies) - Safety assessment (SR 97) - General site investigation programme and programme for site evaluation with criteria - Final report feasibility studies Nyköping, Östhammar	• Review viewpoints on RD&D 98 • SKI statement on RD&D 98 • KASAM statement on RD&D 98 • Government decision on RD&D 98
2000	- Compilation of comparison material - Final report feasibility studies Oskarshamn, Tierp, Municipality X, ...	• International review of safety assessment • SKI's/SSI's viewpoints on safety assessment and site investigation's evaluation programme
2001	- Integrated account of screening material with structured - RD&D-Programme 01 - Programme for site investigations in municipality A and B	• Statement of comment on SKB's and reasoned choice of areas for site investigations supporting material and choice of sites • Concerned municipalities take stand on site investigations
2002	- Site investigations start	

Structuring of facts

The results of all feasibility studies included in the screening material are compiled in a structured manner, employing the long-used structure with siting factors arranged in the main groups safety (geology), technology, land and environment, and society, see Figure 6-8. Descriptions are made of the areas that have been identified in the feasibility studies as being of interest for further studies. Each area's properties in various respects, and the ambiguities and uncertainties associated with the supporting data, are stipulated. Different parties may make different evaluations of the various factors. The structuring of the data should therefore make it easier for others to make their own evaluations.

Evaluation of facts

Each main group of siting factors is evaluated for each area. The most important advantages and disadvantages are singled out. The evaluation is based on the results of the relevant feasibility study. Examples of evaluation grounds are given in the next section.

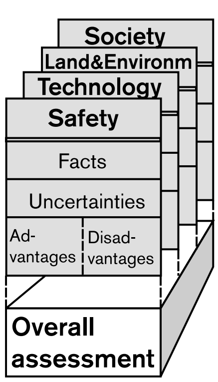


Figure 6-8. *Structuring of facts.*

There will be ample opportunities for evaluating the prospects of the different areas as regards infrastructure, land use, environmental consequences and societal aspects. The opportunities are poorer when it comes to evaluating conditions of importance for long-term safety, since data from the bedrock at repository depth are largely lacking. In the initial stages of the siting process, it is therefore necessary to choose areas based on incomplete and uncertain data. We can, however, make a forecast of probable conditions, including a description of uncertainties and questions that should be given particular attention in continued studies. The siting process must be organized in such a manner that it will be terminated if unsuitable conditions are encountered. It can then be shifted to a new site.

Choice of areas

The choice of areas for site investigations is made on the basis of an overall assessment of all siting factors, see Figure 6-9. Since all areas included in the screening material fulfil the requirements that can be made in this phase of the siting process, they may all be suitable. Data will not be available to prove strictly scientifically that selected sites are the most suitable. It should therefore be clearly specified what facts, judgements and evaluations the choice of sites is based on. It should also be clearly specified what ambiguities and uncertainties exist regarding the properties and conditions of the chosen areas.

The lack of data from repository depth can to some extent be offset by comparisons with other areas in similar geological settings – but where data are available from repository depth. More general databases can also be utilized. This comparison and background material can thereby be used to verify and support the choice of sites. The supporting material used for this includes the safety assessments that have been carried out for some of the areas included in the comparison material.

The areas that are not chosen continue to be of interest for further studies and may be considered if the investigations on any of the sites initially chosen must be terminated. If a new site should have to be selected, this is done in the same way as before, by a structured analysis of areas found to be of interest by the feasibility studies.

6.4.4 Examples of evaluation grounds

When the final choice is to be made among the sites that have been investigated, it is good to have distinct alternatives to choose from. A basic criterion of SKB's is therefore that the selection be made so that the sites are located in different municipalities. The selection will be a question of judgements and evaluations. It is not possible to regulate in detail how different aspects are to be evaluated and weighed against each other. Many important aspects will be specific to each area and cannot be predicted or evaluated in advance. It is therefore important that the screening procedure be known from the start and that it be possible for outsiders to review SKB's selection and clearly see what judgements and evaluations have been applied.

Examples are given in the following of possible evaluation grounds (criteria in this stage of the siting process) for choice of sites for site investigations.

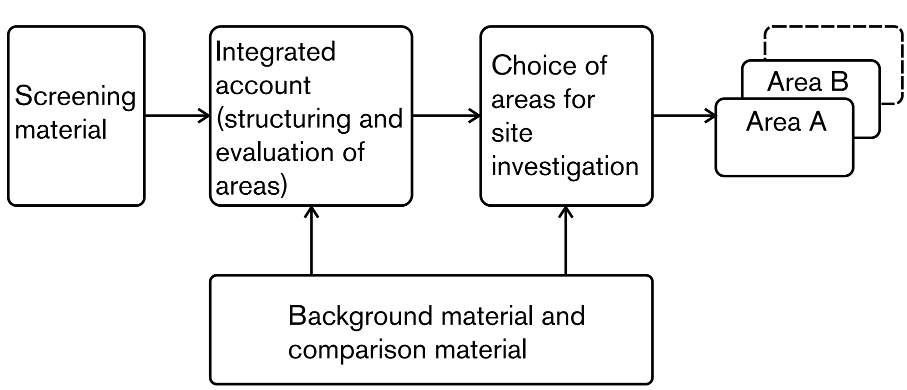


Figure 6-9. *Procedure for site selection*

Long-term safety

Difficult to evaluate the bedrock at depth after feasibility study

The selection will be made among areas that have been identified in feasibility studies as being suitable for further studies. All areas have good prospects of fulfilling the long-term safety requirements. Since no drillings are done in the feasibility studies, there will be varying degrees of uncertainty regarding the bedrock at repository depth. In the choice of areas for site investigations a judgement is made of the importance of the uncertainties, what investigations are needed to eliminate them, and what measures are required to obtain a satisfactory body of data for choosing an area for detailed characterization. The area's size is one important aspect, since a large area offers wider options for dealing with surprises. From this point of view, a large homogeneous area with few uncertainties is valued higher than a smaller and partially inhomogeneous area. The areas are also evaluated in relation to the existing comparison material and the safety assessments that have been done for some of the areas included in it.

Technology and safety in the operating phase

Good chances to evaluate prospects for transportation and construction above ground

The prospects for construction of the deep repository's facilities are evaluated, along with the prospects for transportation to and from the deep repository. For construction of the surface portion of the deep repository, the chances of obtaining a reliable evaluation at this stage are often good, while the prospects are poorer for the underground portion. In general, areas with existing infrastructure are valued higher than areas where new infrastructure has to be built.

Safety and radiation protection in connection with shipments to and at the facilities are important aspects. Although it seems unlikely today that these factors can vary between different sites, analyses will be made for each specific site wherever possible.

Land and environment

Good chances to evaluate areas with respect to land and environment

It is preferable if there are few competing land use interests and if a deep repository in the area in question can be considered to harmonize with the municipality's comprehensive plan (for land use). Further, it is preferable if the site investigations can be carried out with little environmental impact.

Areas with weak nature and culture conservation interests are valued higher from a land-use viewpoint than areas with strong such interests. Areas that do not require long transport on public roads or railway are valued higher from an environmental viewpoint than areas that do. Areas with good options for handling the rock spoils are valued higher than areas that lack such options.

Society

Tricky to evaluate areas from societal point of view

It is difficult to evaluate the qualities of different areas from a societal point of view. Changes can take place rapidly in a society. Furthermore, evaluations from this point of view are largely a question of judgement. As is evident from the commentaries on RD&D-Programme 95, views vary on what weight should be given to public opinion. SKB believes that a positive opinion in the municipality is a prerequisite for establishment of a deep repository. Furthermore, it is favourable if labour is available that suits the needs of the deep repository (for example personnel with experience of rock construction and training in nuclear technology). Municipalities where the demographic forecasts point towards a long-term stable availability of labour, and where the populace is both able and willing to make the most of a deep repository establishment for local and regional development, should in our view be valued higher than municipalities where this is not the case.

The feasibility studies of the inland municipalities Storuman and Malå showed that the prospect of shipments of spent nuclear fuel on public roads or railway worry people who live near the projected transport routes. Even though this worry is not objectively warranted, it is real and may require more public relations efforts than if the deep repository is sited in a coastal municipality. Other societal issues are effects on the travel industry and real estate prices, as well as psychosocial effects.

6.5 Site investigations and site evaluation

Site investigations take 4-8 years

Carrying out a site investigation is estimated to take between four and eight years. SKB reckons that if the choice of two sites is made in 2001, the work can get under way in 2002. The investigation can be divided into two stages: initial and complete site investigations. What is included in the different stages is described in RD&D-Programme 95.

The purpose of the initial stage is to provide a general picture of the bedrock in the area in question. On this basis, the area to be further investigated is more narrowly delimited. If the evaluation of the initial stage shows that the area falls short of expectations, the possibilities of starting investigations in another area are considered. Examples of conditions that can lead to termination of investigations are given later in this chapter. In parallel with the geoscientific investigations, the prospects for transportation to and from the deep repository are investigated, along with environmental and societal aspects.

Safety assessments for each site

Based on the site investigation, SKB conducts site-specific safety assessments. For a site to be eligible for detailed characterization, these assessments must show that there are good prospects that the repository will be safe in the long term. Furthermore, the investigations must show that the repository can be built without great difficulties and that the safety and health of the personnel can be guaranteed during construction and operation. Another prerequisite is that the detailed characterization is deemed likely to dispel whatever uncertainties remain after the site investigations.

6.5.1 Geoscientific site investigations

The goal of the site investigations is to collect geoscientific data needed to determine:

- what the conditions in the rock are like today and how they may change in the future,
- how the repository should be designed in detail and whether it will be safe from a radiological viewpoint for a long time to come.

The phase with site investigations is commenced when SKB has presented the areas chosen as candidates for a deep repository and the investigation activities, including drilling, are begun. Even before then, certain limited geological investigations can be carried out for the purpose of supplementing a feasibility study, although not deep drilling in interesting areas.

SKB has made a compilation of the geoscientific parameters that will in one way or another be of importance during a site investigation /6-30/. Development of criteria and evaluation factors to be applied in evaluating the suitability of the sites is also under way, see section 6.6.

The results of the investigations will be compiled in a geoscientific description of the site. The geoscientific description will be composed of discipline-specific models that are strongly coupled to each other, see Figure 6-10.

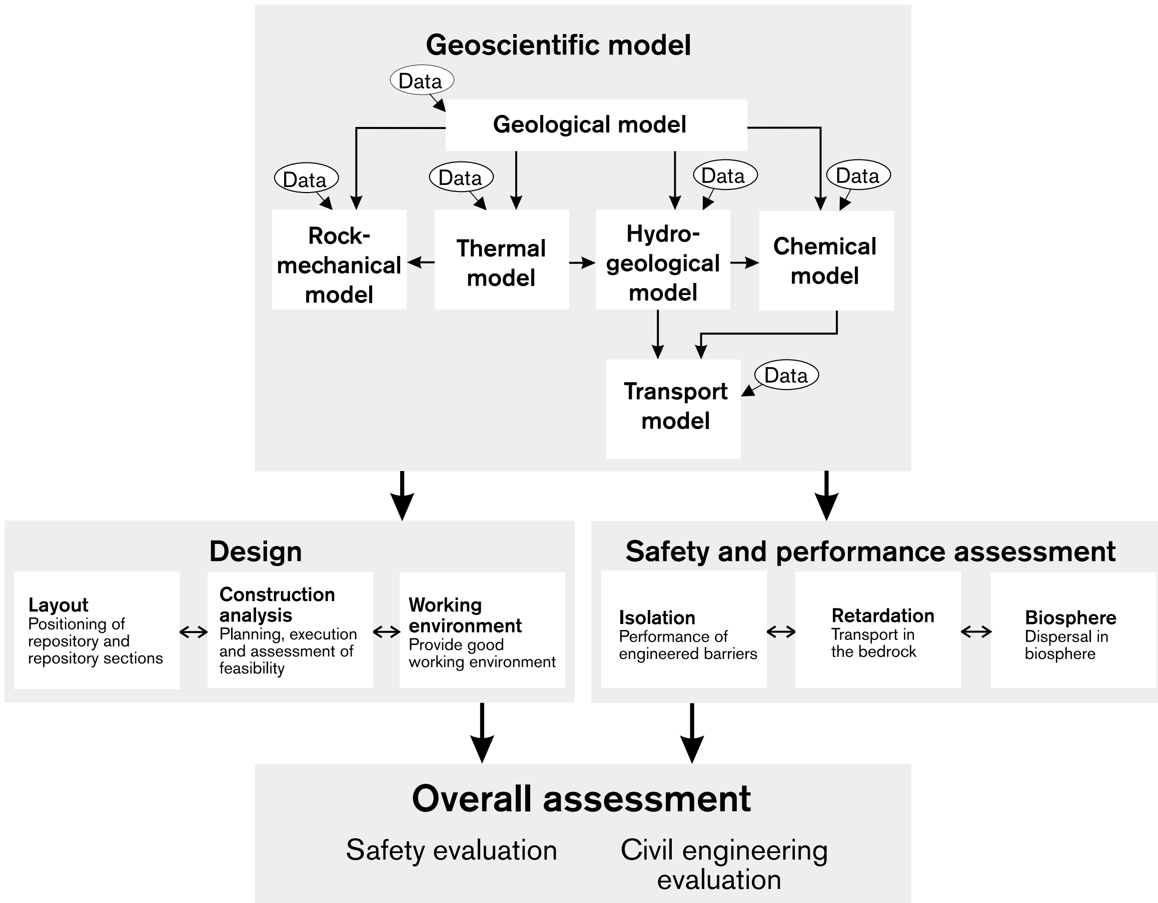


Figure 6-10. *Schematic illustration of how information is transferred between different geoscientific models and how these models are utilized for safety assessment and planning and design of rock works.*

6.5.2 Experience from site investigations

The Äspö HRL has given SKB an opportunity to test and develop methodology for site investigations. Based on the pre-investigations, we made forecasts of geological, hydrogeochemical and rock-mechanical conditions, as well as groundwater flows and premises for solute transport in the rock, before the laboratory was built. Then the forecasts were compared with observations and measurements in tunnels and boreholes underground. Evaluations show that investigations on the surface, combined with analyses and model calculations of various kinds, make it possible to provide a reliable description of the properties and conditions in the rock that are important for a deep repository /6-31, 6-32, 6-33/.

A series of research projects have also contributed valuable experience of geoscientific investigations. This is particularly true of the studies of properties of fracture zones at Finnsjön /6-34/, the Stripa Project /6-35/ and the deep drillings at Laxemar /6-36/.

We can learn from other countries' site investigations

Foreign experience is also available. At present, site investigations are being conducted on four sites in Finland. One of these sites is expected to be chosen in 2000 as a repository site. A description of the Finnish programme for final disposal of spent nuclear fuel is given in /6-37/.

6.5.3 Geoscientific site evaluation

The site investigations will give rise to large quantities of data, which must be analyzed and evaluated. The geoscientific site evaluation is the process that is required to handle the flow of information during the site investigations, make decisions on how to proceed with the work, and evaluate the suitability of the site.

The following is needed to be able to do this in a reasonable time:

- the information flow between different activities must be satisfactory,
- information from the ongoing investigations must be appraised by means of a well-prepared methodology at specified and appropriate points in time.

General site investigation programme is adapted to conditions on selected sites

The site evaluation is supposed to check that fundamental safety requirements and other essential technical prerequisites are fulfilled and that the deep repository is optimally adapted to conditions on the site. The evaluation should also provide a basis for comparing different sites, mainly with regard to long-term performance and safety, but also with regard to other evaluation factors. Figure 6-11 shows which activities are included in the evaluation, interaction between them and what products they contribute.

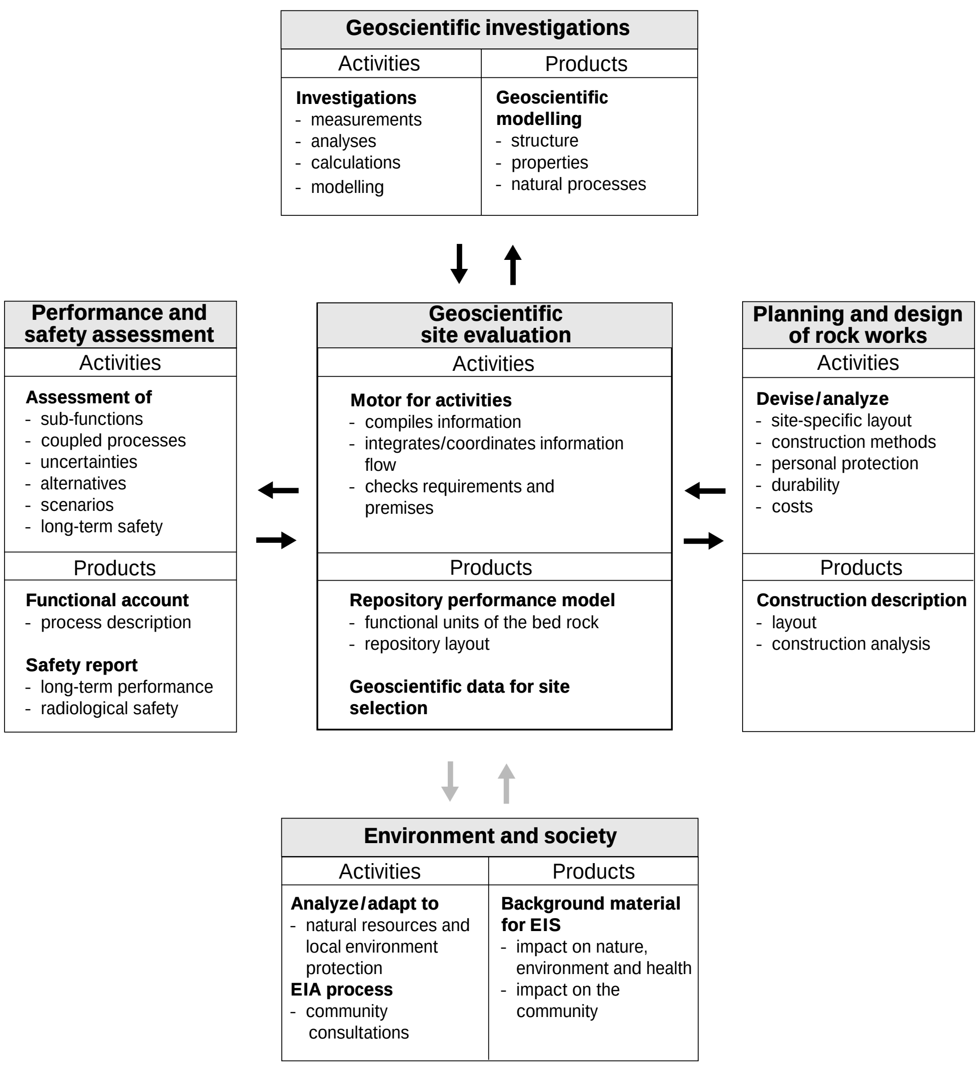


Figure 6-11. *Role of site evaluation as a motor for coordination and information exchange during site investigations.*

6.5.4 Programme for future work

During the coming three-year period, SKB will submit a general programme for site investigations and site evaluation. We will consult with SKI and SSI on this (in compliance with the Government's decision regarding RD&D-Programme 95).

Site investigations should be able to start in 2002. Before then the general programme has to be adapted to the specific conditions on the particular site. The programme should also include a description of the impact of the investigations on the environment and what measures are planned to minimize this impact.

The site investigation programmes will be presented to nearby residents and the municipality within the framework of the EIA process, and their viewpoints will be taken into account in the final planning and execution of the programme.

Other tasks during the next few years are to organize the work in preparation for the site investigations, continue instrument and method development (see section 6.7) and draw up a programme for data management and quality control.

6.6 Criteria for site evaluation

Criteria for how site investigations are to be evaluated must exist before the investigations begin

Before site investigations begin, SKB will present evaluation factors and criteria for site evaluation. A progress report has been published in which requirements and preferences for repository host rock are presented /6-38/.

6.6.1 Terms and definitions

Various terms are often used in connection with siting, investigation and evaluation to stipulate whether a site possesses the necessary characteristics for complying with the safety requirements made on a deep repository. Terms such as requirements, preferences, evaluation factors and criteria have therefore been clarified. Our proposals for definitions of these concepts are given in Table 6-5. The term "siting factor" has not been included in the table, since siting factors is to be regarded as a collective name for all the factors to be taken into account in evaluating sites, including technical, environmental and societal conditions. Certain siting factors cannot be dealt with objectively, making subjective judgements necessary. An example is the different outlooks that may exist regarding the impact of the deep repository on the local community.

Requirements and preferences regarding the performance and safety of the repository can be set up from the start and are the same throughout the siting process. Evaluation factors and criteria are dependent on what can be known at a given stage and must therefore be chosen with a view to the knowledge that is available when an assessment must be made.

In the initial stages of the siting process only general data are normally available. At these stages it is not possible to specify detailed criteria. Site investigations, however, furnish data that render detailed criteria meaningful.

In the operation of the deep repository, new criteria can be stipulated to meet the requirements made by SKB and/or the safety authorities on performance, safety and radiation protection. They may, for example, pertain to the stability of tunnels and water seepage in deposition holes.

The evaluation of the safety and technical performance of the deep repository is based, among other things, on combined results of safety and performance assessments and construction analyses. These are in turn based on a geoscientific model of the repository area based on measurement data and observations from the site in question.

From general safety requirements, specific functional requirements can be derived, which in turn can lead to specification of limit values and requirements for certain parameters (for the rock). This is not always meaningful, however, since the repository can often be adapted to the conditions on a specific site without compromising safety. The safety of a deep repository on a given site must in the end always be evaluated by means of an integrated safety assessment using data from that particular site. Definitions of the terms "parameter" and "function" are given in Table 6-6.

Table 6-5. Terms proposed to be used for investigation and evaluation. The examples pertain to a KBS-3 repository and are based on present-day knowledge

Term	Definition	Example
Requirement	Refers to conditions that must be satisfied. May relate to either function or parameter.	The salinity of the groundwater at repository depth may not exceed 100 g/l (TDS) if the bentonite is to retain its isolating function.
Preference	Refers to conditions that ought to be satisfied. May relate to either function or parameter. Satisfying preferences generally leads to lower costs, simpler investigations and/or simpler engineering of the repository. All preferences do not have to be satisfied for a site to be approved for a deep repository.	The radon levels should not occasion abnormal ventilation requirements.
Evaluation factors	Measurable or estimable site-specific properties and conditions that can be used in a given siting stage to determine whether the site will satisfy requirements and preferences.	*In feasibility study:* Salinities in wells. Natural radiation of the bedrock. *In site investigations:* Salinity at repository depth. Radium concentration and hydraulic conductivity at repository depth.
Criteria	Indications (measures) of whether one or more evaluation factors will satisfy requirements and certain preferences on completion of the facility. Criteria may be different in different siting stages.	*In feasibility study:* Salinities in wells should not exceed that of seawater. Areas with sharply elevated radiation levels should be avoided. *In site investigation:* The salinity of the groundwater at repository depth may not exceed 100 g/l TDS. Radium concentrations together with hydraulic conductivity should not increased unmanageably high radon levels in the finished repository.

TDS

Total Dissolved Solids

Table 6-6. Definitions of parameter and function when identifying requirements, preferences, evaluation factors and criteria

Term	Definition	Example
Parameter	Physical/chemical property and condition	Thermal conductivity
Function	Purpose which the deep repository is intended to serve.	Temperature on canister surface with the conditions that prevail on a specific site.

6.6.2 Requirements and preferences regarding repository performance

Based on general safety requirements, SKB has in previous reports, mainly in the supplement to RD&D-Programme 92 and in the feasibility studies, formulated functional requirements and preferences regarding the isolating function of the deep repository, its retarding function and recipient conditions. The work of designing the deep repository is similarly based on requirements and preferences with regard to layout, construction analysis and working environment.

Fundamental requirements on the deep repository

Regulations for the deep repository are currently being framed by SKI and SSI

There are fundamental requirements that must be met by a deep repository. These are defined by laws and regulations issued by the regulatory authorities. Regulations for the deep repository are currently being framed by SKI and SSI. The question of whether the fundamental requirements are met by a deep repository on a specific site is considered when the authorities review the safety assessments and environmental impact statements that SKB will submit in support of an application for a siting permit.

SKB's requirements and preferences regarding safety

SKB has in various contexts presented a detailed set of requirements on the performance of the deep repository. An important part of this account was produced in conjunction with the supplement to RD&D-Programme 92, where fundamental safety requirements on a deep repository were stipulated, along with generally favourable conditions and conditions that occasion termination of the investigations on a site. Based on these requirements and conditions, siting factors were identified, see Figure 6-12.

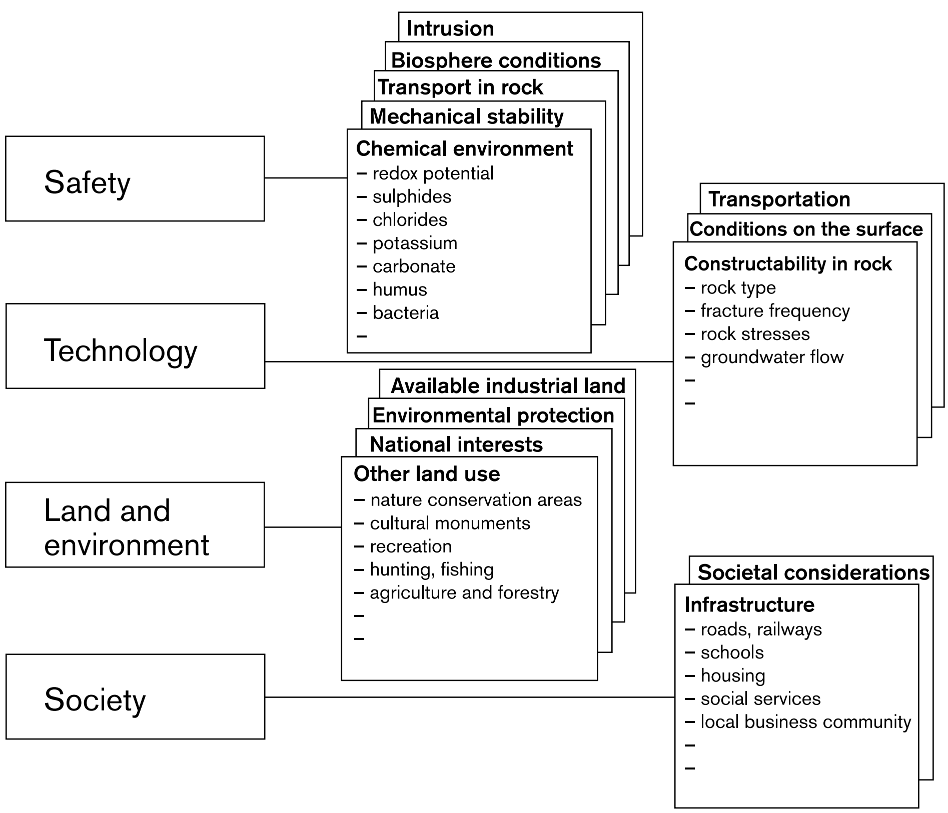


Figure 6-12. *The structure for discussion concerning requirements on safety functions and siting factors that was introduced in conjunction with the supplement to RD&D-Programme 92.*

SKB's requirements and preferences regarding the performance of the deep repository can be formulated as follows:

- *Isolation canister* – The canister shall isolate the waste from its surroundings.
- *Isolation bentonite* – The bentonite shall contribute to the isolation of the waste, mainly by creating favourable conditions for the canister.
- *Isolation rock* – The rock shall contribute to the isolation of the waste, mainly by creating favourable conditions for the bentonite and the canister.
- *Intrusion* – The waste shall be protected against intrusion to prevent voluntary or involuntary exposure.
- *Retardation fuel* – Dissolution of the waste, i.e. release of radionuclides, shall take place very slowly.
- *Retardation canister* – The canister shall, if isolation fails, prevent or retard the transport of radionuclides from the fuel to the bentonite.
- *Retardation bentonite* – The bentonite shall prevent or retard the transport of released radionuclides to the rock/geosphere.
- *Retardation rock* – Transport of radionuclides (as well as transport of groundwater with undesirable chemistry) shall be retarded.
- *Biosphere* – Effective radiation doses to individuals in the critical group shall not exceed levels specified in SSI's regulations. Furthermore, the impact of the deep repository on biological diversity shall be small. A preference is that dilution should take place to low concentrations before readily mobile radionuclides reach the biosphere.

Bentonite
Clay, usually of volcanic origin

Detailed requirements and preferences regarding repository performance

In the aforementioned report on evaluation factors /6-38/, a detailing of requirements and preferences has been done with the aid of tables divided into the disciplines chemistry, hydrogeology, transport properties in rock, thermal properties, rock mechanics and geology. Each discipline gives rise to a table in which the division into rows is determined by the general requirements on safety functions. The factual content of the tables is determined in expert groups. Scientific advances and experience from safety assessments necessitates recurrent review of the factual contents. Work on the function tables is under way. The following conclusions can be noted from the work to date:

- There are relatively few requirements. However, it is possible to identify a large number of parameters and conditions where preferences exist regarding suitable value ranges. This is due to the fact that it is the combined influence of numerous factors that determines whether an area is suitable or not.
- The preferences indicate value ranges that can be more precisely defined by means of performance assessments. They may furthermore contain some requirements that have not yet been quantified but emerge through performance assessments.
- Requirements and preferences need to be checked against the safety assessment, SR 97. Parts of the performance assessments described in the tables are being carried out within the framework of SR 97.

6.6.3 Geoscientific evaluation factors

The performance of the deep repository was discussed in the preceding section. In some cases, it is also possible to discuss requirements and preferences with regard to individual parameters, based on requirements and preferences with regard to repository performance. The term "parameter" has been given a very broad interpretation and can consist of measurable data, interpreted information or derived parameters for a given descriptive (conceptual) model.

SKB has identified which geoscientific parameters are to be determined in a site investigation /6-30/. They constitute evaluation factors if one of the following conditions is fulfilled:

- A direct requirement or an essential preference has been formulated for the parameter.
- The parameter has an anticipated great influence on the result of one or more important performance assessments.

Redox capacity (Eh)
Capacity to consume an oxidizing substance, e.g. oxygen

Each geoscientific discipline gives rise to a table which has been divided into rows according to all of the geoscientific parameters determined in a site investigation. Requirements and preferences are given for each parameter, resulting in an assessment of whether it is considered to be an evaluation factor. Furthermore, probable ranges within which the parameter varies and what knowledge can be attained in different stages of the siting process are stipulated. An example is shown in Table 6-7. The example is taken from the discipline "groundwater chemistry", more precisely the parameter redox capacity, Eh.

The factual contents of the tables are determined in expert groups. Representatives of different scientific disciplines are assembled and work according to the methodology described here. Recurrent review of the factual contents is necessary. Work on the parameter tables is under way. The following conclusions can be noted from the work to date:

- The tables are above all necessary to obtain systematics in the work. Descriptive texts are also needed for a complete account. Such texts are written in connection with each table, i.e. for each discipline.
- As a rule, it is difficult to directly stipulate the requirements on a geoscientific parameter. The parameter is sometimes only one of several parameters that determine a function, and the permissible value range is often dependent on the value of the other parameters. The parameter can also influence several functions, and good value ranges for one function are not necessarily good for other functions.
- The value ranges that are analyzed in the ongoing safety assessment SR 97 will be a valuable aid in concretizing preferences later on.
- To determine whether a parameter is a suitable evaluation factor, but above for making a judgement based on requirements and preferences, knowledge is required of what precision can be expected in the parameter estimate. Knowledge of the parameter increases from the feasibility study, site investigation and detailed characterization. However, the importance of the different investigation steps varies greatly between different parameters. Naturally, the level of ambition for the different investigation stages can also influence to what extent a parameter can be determined.

Conditions that occasion termination of the investigations

The work of defining what requirements and preferences the site should fulfil also includes defining conditions that occasion termination of the investigations on that site. Such discriminating conditions are described in the supplement to RD&D-Programme 92. These conditions are the following:

- Extreme groundwater chemistry, for example oxidizing groundwater.
- Exploitable ores or minerals in the repository area.
- Many close-spaced water-bearing fracture zones.
- Extreme rock-mechanical conditions, such as high rock stresses and/or low rock strength.

Table 6-7. Structure used to identify and justify geoscientific parameters of importance for a deep repository (evaluation factors)

Geoscientific parameter	Eh
Requirements	Insignificant occurrence of dissolved oxygen at repository depth. Indicated by low Eh, Fe(II) or sulphide in the groundwater.
Preferences	The value of Eh is a function of pH and Fe(II). For pH around 7, the preference is that Eh < - 100 mV.
Value range in Swedish crystalline bedrock	Nearly ideal conditions prevail at depths below 100 m. Eh in the range - 308 mV - (- 202 mV) is used for the safety assessment SR 97.
Suitable/conceivable evaluation factor and reason	YES - since the parameter is linked to requirements and strong preferences.
Knowledge that can/should be achieved after feasibility studies, site investigation and detailed investigation	*Generic*: See value ranges. *Feasibility study*: Adds nothing new. *Site investigation*: Water samples from boreholes permit qualified estimation. *Detailed characterization*: No essential new knowledge.

In conjunction with the detailing of requirements and preferences currently in progress, the list of discriminating conditions is being updated and augmented. Individual parameters will be described in this work. If a requirement on an individual parameter is not satisfied, this occasions termination of the investigations on the site. Even if all parameters in a site evaluation satisfy the requirements, an integrated safety assessment is required to show whether the site is suitable or not.

6.6.4 Programme for future work

SR 97
will be important for determining requirements and preferences regarding the deep repository

In conjunction with RD&D-Programme 98, SKB is publishing a progress report regarding requirements and preferences with regard to functions in the deep repository and with regard to parameters and evaluation factors. When we have solicited internal and external viewpoints, SKB will present an updated and complete proposal of criteria that can be used during and after site investigations. The results of the safety assessment SR 97 will be an important basis for this work. After viewpoints have been incorporated, a final report will be presented.

The work of identifying evaluation factors and criteria is closely linked to the work of devising programmes for site investigations. It is important firstly that the important parameters are really measured in the site investigations, and secondly that the site evaluation particularly deals with the functions of the deep repository that are linked to requirements and preferences regarding the properties of the site and the repository. At the same time, the criteria should relate to parameters that are possible to measure or estimate. The work of preparing programmes for site investigations and criteria for how these are to be evaluated will therefore be conducted in parallel during the coming three-year period.

6.7 Instrument and method development for site investigations

Measurement methods and instruments for site investigations must be maintained and refined to keep up with global advances in technology. Several of the instruments that are used in the Swedish nuclear waste programme are so advanced or specialized that they are not available on the market. This means that SKB has to conduct development and take responsibility for the availability of the technology. For this reason we own our own instruments and measurement systems and organize storekeeping and servicing ourselves. The need for equipment and skills for site investigations is further underscored by the fact that investigations are intended to be conducted in parallel on at least two sites. This will lead to some acquisition of new instruments during the next few years.

Programmes for development of specific instruments and methods during the coming three-year period are described below. Besides instrument and method development, we will during the next few years inventory what resources are available to ensure that we can carry out parallel site investigations.

6.7.1 Surface geophysics

Site investigations are begun by surveying bedrock conditions from the ground surface. Geophysical measurements, among others, are used for this purpose. Extensive experience of these methods is available from the study sites and Äspö. New electrical methods have been tested in recent years. One purpose has been to see whether it is possible to detect the depth to saline groundwater. Several tests are planned during the coming years before the practical value of these methods can be established.

Another method deemed to have great potential for improvements is seismic reflection. Encouraging results have been obtained from tests in the Finnsjön area and on Ävrö. Further field tests of this method are planned in different geological environments. A newly-developed program for modelling of the bedrock (RVS) will be tested in connection with the interpretation of seismic data.

Other seismic studies concern three-dimensional seismic reflection surveying programmes and how data from seismic surveys in deep boreholes (VSP) can be co-interpreted with seismic reflection data.

RVS

Rock Visualisation System

Computer program for visualizing boreholes, tunnels, measurement results and geological objects in three dimensions

VSP

Vertical Seismic Profiling

Seismic measurements between borehole and ground surface

GPS

Global Positioning System

Position determination with aid of satellites

6.7.2 Position measurement

GPS will be used increasingly to determine the position of measurement points and boreholes on the ground surface, while traditional surveying methods will still be used where high accuracy is required. As far as measurement of the direction and deviation of the boreholes is concerned, available methods are judged to be satisfactory. However, the accuracy of the length measurement is unsatisfactory for certain borehole probes. The development of a borehole length calibration system described in RD&D-Programme 95 has been tested in the field. The method did not meet the functional requirements. The development work has therefore switched to another technical direction, where grooves at determined depths are cut into the borehole wall. A field test was recently performed with good results.

6.7.3 Drilling technology and measurements during drilling

Cave-ins can occur during drilling in unstable sections of the borehole. A method is therefore needed that can keep the boreholes intact better than now. Advantages and disadvantages of different methods for stabilizing boreholes will be evaluated during the coming three-year period. The records from the drilling work will be re-evaluated so that we can derive greater benefit from the information provided by drilling.

SKB has established a new instrument store with associated workshop adjacent to the Canister Laboratory in Oskarshamn. A borehole where equipment can be tested is planned to be drilled from the store. Methods related to drilling and tests during drilling will be tried out when this hole is drilled.

Posiva

SKB's counterpart in Finland

6.7.4 Methods for hydraulic tests and groundwater chemistry

The investigations on Äspö, Stripa and the study sites have entailed the development of several different methods for determining hydraulic conductivity, measuring groundwater pressure, determining groundwater flow and detecting hydraulic interconnections between boreholes. A review of different measurement and evaluation methods used in connection with hydraulic tests has been carried out by a group consisting of representatives from SKB's and Posiva's geo-programme /6-39/. The Group's conclusion is that well-proven methods for hydraulic tests exist now, but that they need to be developed with respect to the representativeness of the measurement data and resource needs. Examples of what needs to be done are:

- procure another pipe string system so that two site investigations can be conducted at the same time,
- modernize mobile umbilical hose systems for both hydraulic tests and groundwater sampling,
- test the Finnish differential flow log for measurement of hydraulic parameters,
- try out suitable methodology for flow logging in deep boreholes with saline groundwater,
- develop methods for determination of absolute groundwater pressures.

Water sampling in conjunction with drilling offers good prospects for obtaining undisturbed water samples. Technology for this has been developed and tested in the field. Further development of the method will be pursued during the coming three-year period.

Pipe string system

Measuring equipment where interconnected pipes are used to take water samples or measure the hydraulic conductivity of the bedrock in boreholes

Umbilical hose system

Measuring equipment enabling water samples to be taken or the hydraulic conductivity of the bedrock to be measured in boreholes via a long hose

Differential flow log

Instrument for measuring hydraulic conductivity in boreholes

6.7.5 Borehole geophysics and rock stress measurements

SKB has developed a method for integrating the mapping of drill cores with TV images (BIPS images). The method improves the efficiency of the geological borehole records while improving quality at the same time. During the coming years we will try integrating geophysical interpretation, radar and borehole seismic methods in this borehole documentation.

Regarding rock stresses, SKB has access to the two complementary methods overcoring and hydraulic fracturing. The latter was recently modernized in conjunction with the installation of a new 1,000 metre umbilical hose system.

BIPS

Borehole Image Processing System

Borehole television which, besides showing pictures of the borehole wall, can calculate fracture orientations

6.7.6 Data management and quality assurance

Traceability

Ability to trace how the value of a given quantity has been obtained back to original measurement data

The tools and basic routines for data management and quality assurance that have been devised at the Äspö HRL will be applied during the coming site investigations. The SICADA database and the recently developed three-dimensional program for visualizing the bedrock (RVS) will be tried out and developed in conjunction with ongoing investigations in the Äspö HRL.

We continuously revise and improve instructions and technical documentation of investigation methods and instruments. The purpose is to achieve full traceability in all investigations and data evaluations. An analysis of safety and health for the investigation personnel and of the environmental effects of investigation activities is included in the quality and safety work.

7 Technology

The work of developing the technology for the deep disposal system has been going on for more than 20 years. We have now reached the point where components and sub-systems can be tested on a full scale and in a realistic environment. This represents the beginning of a new phase in the technology development work.

The Canister Laboratory which SKB has recently built in Oskarshamn will be a centre for development of encapsulation technology and training of personnel for the encapsulation plant. At the same time, the technology for fabrication of copper tubes and cast inserts is being further developed. At the Äspö HRL, tests are planned which simulate on a full scale all steps in the deep disposal process: boring of deposition holes, emplacement of canisters and bentonite buffer, backfilling and closure/sealing. In addition, technology for possible retrieval of previously deposited canisters will be developed.

The development work at the Canister Laboratory and the Äspö HRL, along with other technology development and existing knowledge, comprise the basis for the ongoing technical planning of the encapsulation plant and the deep repository. The site investigations will then provide the data needed for adapting the deep repository to the bedrock on the site and other local conditions.

7.1 Fundamental technical requirements

The primary function of the deep repository is to *isolate* the waste. The canister provides direct isolation, but the buffer and the rock are also needed for the canister to fulfil its isolating function. These barriers must satisfy a number of requirements to provide good isolation.

If this isolation should be breached, the deep repository is also supposed to *retard* the transport of radionuclides from the fuel. The canister, the buffer and the rock work in conjunction to provide this function as well. The retarding function makes additional demands on the barriers.

To the requirements related to long-term safety are added requirements related to fabrication, construction and operation.

7.1.1 Requirements on the canister

As long as the canister is intact, all dispersal of radioactivity to the surrounding environment is prevented. If a penetration should occur in the canister, the other barriers will retard and attenuate the dispersal of radionuclides to acceptable levels. The requirements made on the canister can be divided into requirements related to the isolating function and requirements related to the retarding function. To achieve isolation, the canister must:

- be leaktight on emplacement,
- be resistant to the chemical environment anticipated in the deep repository,
- be able to withstand the mechanical loads anticipated in the deep repository.

Chemical resistance means that the outside of the canister must not be affected by corrosive substances in the groundwater or by any harmful substances that may be introduced during construction of the repository. Moreover, the canister must not corrode internally as a consequence of the harmful substances that may remain or be formed in the canister.

The mechanical loads to which the canister is exposed in the deep repository are caused by the pressure exerted by the groundwater and the swelling bentonite. Future ice ages or major rock movements can also give rise to mechanical stresses on the canister.

Criticality

Under certain conditions (for example in a nuclear reactor), atomic nuclei undergo fission in a self-sustaining chain reaction

To ensure the retarding function, the canister must influence the chemical properties of the buffer and the rock as little as possible. This means that the heat flux and radiation dose to the near field must be limited. The canister must be designed so that the release of radionuclides is retarded if the canister is damaged. The material of which the canister is made must not affect the rate of dissolution of the fuel or radionuclide transport through buffer and rock. The canister design must also ensure that criticality can never occur, even if water should enter the canister.

The requirements mentioned above pertain to the long-term safety of the deep repository. In addition, the canister must be designed to ensure high safety during encapsulation, transport and deposition. The canister must meet the requirements made in connection with both normal and abnormal operating conditions during handling. This means that the canister must be able to be handled so that foreseeable accidents do not lead to unacceptable radiation doses to the personnel or releases of radioactivity to the environment. The canister must be able to be transported, deposited and, if necessary, retrieved from the deep repository in a safe manner. Another requirement is that the canister must be able to be serial-fabricated to specified quality requirements.

BWR

Boiling Water Reactor

PWR

Pressure Water Reactor

Fuel channel

Casing that surrounds the fuel rods in a BWR assembly

All fuel types that are stored in CLAB must be able to be encapsulated in canisters with the same overall dimensions. BWR fuel must be able to be encapsulated together with its fuel channel and PWR fuel with control rods. The canisters must also be able to be used for encapsulation of fuel assemblies containing damaged fuel rods.

7.1.2 Requirements on the buffer

The requirements on the buffer can, like the requirements on the canister, be divided into requirements related to the isolating function and requirements related to the retarding function. For the isolating function, the buffer must:

- completely enclose and protect the canister for a long period of time, and keep it centred in the deposition hole,
- prevent groundwater from flowing through the buffer and thereby prevent corrosive substances from being transported to the canister in any other way than by diffusion.

Sorption

Adherence of solutes to, for example, fracture surfaces

Colloids

Particles that are so small they don't sink to the bottom of liquids

These requirements in turn require that the buffer should remain in the deposition hole and that it should be chemically stable over a long period of time. Another requirement is that the buffer should efficiently conduct heat away from the canister.

Several of the requirements relating to the isolating function also relate to the buffer's retarding function. For this function, the buffer must create conditions where radionuclide transport takes place by diffusion and where radionuclides sorb on the surface of the clay particles. The buffer must also filter colloids that may form on dissolution of the fuel. Gas that may form inside a damaged canister must be allowed to escape.

As far as the operating period is concerned, blocks of buffer material must be able to be fabricated, transported and emplaced in the deposition holes in a manner that guarantees the necessary quality.

7.1.3 Requirements on the bedrock

The host rock also has an isolating and a retarding function. For the isolating function, the bedrock must:

- constitute a mechanically stable environment for the deep repository,
- provide a chemical environment that is long-term stable and favourable with respect to the function of the other barriers,
- minimize the risk of future intrusions and alternative uses (e.g. mines).

For the retarding function, the composition of the groundwater must be such that the solubility of the radionuclides is limited. The bedrock must also limit the transport of the radionuclides with the groundwater to the biosphere.

To the requirements relating to long-term safety are added requirements relating to construction and operation. The bedrock must possess such properties that the deep repository can be built and operated with adequate safety and known technology. This means, among other things, that it must be possible to construct stable rock excavations and that it must be possible to operate the repository with good control of excavation stability and groundwater seepage.

The properties of the engineered components of the system – canister, buffer, backfill and closure/sealing – can be influenced by material choice, engineering and fabrication processes. The same cannot be said about the bedrock. For this reason, the procedure followed to meet the requirements on the bedrock is fundamentally different than for the other components. The principle is to select a site, with the aid of increasingly detailed investigations, where the bedrock satisfies the fundamental requirements while also providing other favourable conditions, and to adapt the layout of the repository to conditions on the site.

7.1.4 Requirements on the backfill material

When the canisters have been emplaced the deposition tunnels are backfilled. Other spaces in the deep repository are also planned to be completely backfilled when all canisters have been emplaced. The backfill material to be used should contribute to tunnel stability and hold the bentonite around the canisters in place. The backfill is also supposed to prevent or limit the flow of water around the canister positions. Furthermore, the backfill material should not cause deterioration of the quality of the groundwater and should remain chemically stable over a long time.

7.1.5 Requirements on the seals

The tunnels and shafts in the deep repository may need to be sealed, temporarily or permanently, with plugs. Temporary plugs will be needed during the operating phase to separate backfilled deposition tunnels or other areas that need to be temporarily separated from areas that are open and accessible. The requirements on these seals are that they should firstly hold buffer and backfill material in the closed-off area in place, and secondly prevent or reduce water transport from the closed-off area inside the plugs to the open area outside.

Permanent seals may be needed to reduce water flows in or along tunnels or to isolate tunnel sections that are intersected by water-bearing fracture zones. A more precise definition of the requirements on permanent seals requires access to data from the specific site and to results of performance assessments.

7.2 Canister design

Canister design proceeds stepwise by compilation of basic premises, property requirements and design premises. At the same time, practical trials are conducted with fabrication and sealing of canisters. The final canister design will be a result of both theoretical analyses and practical trials.

Basic premises and property requirements emanate from the requirements that are made on the canister according to section 7.1.1 and lead to certain design premises. They are based on the results of assessments of long-term safety in the deep repository and on safety in handling. The canister's design premises and design are summarized below. A more detailed account is given in /7-1/.

7.2.1 Design premises

Integrity

MPa, Megapascal

Pressure is given in the unit Pascal

1 Megapascal = 1,000,000 Pascal

Hydrostatic pressure

Pressure from overlying water

Swelling pressure

The bentonite buffer swells when it absorbs water, which gives rise to pressure on canister and rock

The canister must withstand all known corrosion processes so that it can be expected to remain intact in the deep repository for at least 100,000 years. The methods for fabrication, sealing and inspection must guarantee that only a few canisters can contain defects that could lead to water entering the canister earlier than expected.

The canister must be designed to withstand the mechanical stresses that arise in a deep repository in granitic rock down to a depth of 700 metres. This means that the canister must withstand a load of up to 7 MPa of hydrostatic pressure from the groundwater, plus about 7 MPa of swelling pressure from the bentonite. These loads act on the canister from all directions and are assumed to be independent of each other, which means that the canister must withstand a total of up to about 14 MPa of external pressure. The canister should be designed for this load with the customary safety margins (a factor of 2.5 for this type of design). This means that the canister should be designed for an external pressure of 35 MPa.

The calculated strength of the canister must take into account loads that can be expected during an ice age. With an assumed maximum ice thickness of 3,000 metres and a corresponding increase in the groundwater pressure, the maximum external pressure to which the canister could be subjected is 44 MPa, which is regarded as an extreme case for which no extra safety margins are required. Thus, the load during an ice age is the design-basis load case.

During the time the bentonite is absorbing water and the swelling pressure is developing, the pressure on the canister from the bentonite may be unevenly distributed. Certain disequilibria in the load distribution may persist even after the bentonite has become saturated with water. In design calculations, residual loads are handled with the customary safety margins. No extra safety margins are applied for transient disequilibria in load distribution.

Impact on other barriers

Surface dose rat

Radiation per unit time is given in Grays per hour (Gy/h)

One of the requirements made on the canister is that the canister material must not appreciably impair the performance of the buffer or otherwise lead to the integrity of the canister being threatened. This is also true of the canister material's corrosion products. To satisfy this requirement, the external temperature on the canister must not exceed 100°C. The surface dose rate must not exceed 1 Gy/h. The design of the canister must also ensure that criticality can never occur, even if water should enter the canister.

Handling

The canister design must permit serial fabrication of approximately 200 canisters per year in compliance with specified quality requirements. Foreseeable handling accidents during encapsulation, transport and deposition must not cause unacceptable radiation doses to the personnel or releases of radioactive materials to the environment. The canister must furthermore be designed so that it can be retrieved from the deep repository in a safe manner.

7.2.2 Canister design

Material selection

To satisfy the requirement on chemical resistance in the environment prevailing in the deep repository, copper has been chosen as a barrier to corrosion. Copper is judged to possess the required service life, as well as to cause minimal impact on other barriers in the deep disposal system.

As far as mechanical strength is concerned, the canister must withstand 44 MPa, see section 7.2.1. A copper canister cannot be made self-supporting under loads of this magnitude. Its load-bearing capacity must therefore be improved by filling the void in the canister with a material that can absorb portions of the pressure or by providing the copper canister with a pressure-bearing insert.

Design of the reference canister

The reference canister chosen by SKB consists of an outer corrosion barrier of copper and a pressure-bearing insert of spheroidal graphite (nodular) iron, see Figure 7-1. The canister holds either twelve BWR assemblies or four PWR assemblies. Its diameter is 1,050 mm and its length is 4,830 mm. The total weight, including fuel, of a BWR canister is about 25 tonnes, and of a PWR canister about 27 tonnes.

The copper material is equivalent to UNS 10100 (or EN 133/63, Cu-OF1) with an addition of about 50 ppm phosphorus to increase the material's creep ductility. To give it the required corrosion protection the wall thickness must be at least 15 mm. Conservative estimates show that this thickness, for 100,000 years, gives a safety factor of 3 against corrosion penetration. These estimates also take into account the possible inflow of oxygenated water in conjunction with the retreat of a continental ice sheet.

The pressure-bearing insert is made of spheroidal graphite iron equivalent to SS 14 07 17. In fabrication the insert, with bottom, is cast in one piece. The insert's lid is made of steel and screwed on with a bolt in the centre. The lid has a valve which permits the air in the insert to be replaced with inert gas without the lid having to be lifted off. The spacing between the fuel channels is 50 mm and the minimum distance from the fuel to the outside of the insert is 50 mm. The critical external pressure for a cast insert for BWR fuel, which has the lowest strength, has been calculated to be about 80 MPa. This is nearly twice as much as what is required, see section 7.2.1. Check calculations show that the insert possesses sufficient strength for all design-basis load cases.

Figure 7-1. *Copper canister with insert of cast iron for BWR fuel.*

Spheroidal graphite iron (nodular iron)
Cast iron that is treated in a way that gives it good mechanical properties

Creep ductility
Property which indicates how ductile the material is during slow deformation

Experimental studies have shown that the corrosion properties of the spheroidal graphite iron in the conditions assumed to prevail in the deep repository are at least as good as the properties of the engineering steel studied previously /7-2/. Further experimental studies, above all of the course of corrosion in the gap between the insert and the copper canister, will nevertheless be carried out. Since spheroidal graphite iron has much better castability than cast steel, spheroidal graphite iron has been chosen as the reference material in the insert.

In order to meet the requirement on a maximum permissible surface dose rate of 1 Gy/h, the canister must have a minimum total material thickness of 100 mm. The chosen design of the insert therefore leads to the requirement that the wall thickness of the copper canister must be 50 mm. However, if only corrosion protection is taken into account, the copper thickness can, as mentioned before, be reduced to 15 mm. The design of the insert would then have to be modified so that the total material thickness is still 100 mm. When the requirements on corrosion resistance and mechanical strength are weighed together with the requirements of fabrication and handling, 30 mm appears to be a suitable wall thickness. Fabrication trials with a 30 mm copper canister are currently under way.

Hot isostatic pressing
Compression moulding of powder under high pressure and high temperature

SKB has previously studied other canister designs. In one alternative, the void in the copper canister is filled with molten lead, and in another alternative a solid copper canister is fabricated by means of hot isostatic pressing. Both of these alternatives are probably practically feasible, but they require that encapsulation take place at a high temperature, which is avoided with the present reference canister. With the "cold" encapsulation process that is now planned, the risks associated with encapsulation are limited. This has been decisive in the choice of canister design, since long-term safety is deemed to be equivalent for the three canister alternatives.

Sealing and nondestructive testing

Electron beam welding
Welding with a thin electron beam which fuses the parts together

TWI
The Welding Institute Cambridge, England

The reference canister has a horizontal weld surface between the copper lid and the copper tube. Lid and tube are joined together by electron beam welding in a vacuum. To prevent molten copper from running out during welding, it has been necessary to provide the lid with an external support edge. The edge may, however, make it difficult to place the lid on the canister by remote control during handling in the encapsulation plant. To avoid this, an alternative design with an angled weld surface has been tried at TWI in Cambridge. The welding trials showed good results, but indicated that certain problems exist with stability in the molten zone during welding. Continued trials with angled electron beam welding will therefore be conducted at the Canister Laboratory.

At Uppsala University, methods are being developed for nondestructive ultrasonic testing of copper welds. Besides laboratory tests, programs for modelling the propagation of ultrasonic waves in copper and methods for reducing the noise are being developed and tested. At the same time, methods for nondestructive testing with X-rays are being developed. Most of this work will be done in the Canister Laboratory in the future.

7.2.3 Programme for future work

In its review of RD&D-Programme 95, SKI pointed out that certain canister questions needed to be explored further. They included the creep properties of the phosphorus-containing copper which SKB had chosen as a canister material. The causes of the increase in the creep ductility of copper when phosphorus is added are currently being investigated and the work is expected to continue during the coming three-year period. The same applies to creep testing of the copper material used in the trial fabrication of canisters.

Viewpoints that have been offered on SKB's corrosion studies have been taken into account during the past three-year period. Work is under way to update the thermodynamic database for copper and experimental studies are being conducted of the conditions for and modelling of pitting corrosion. More exhaustive studies of the conditions for bacterial corrosion are also in progress. The results of these studies will determine to what extent additional work is required. Studies of the susceptibility of the copper grades being considered to stress corrosion cracking are under way and are planned to continue during the coming three-year period.

In our opinion, the knowledge base concerning copper corrosion will be sufficient after completion of the aforementioned studies to permit reliable estimates of the canister corrosion that will occur during 100,000 years in the conditions projected to prevail in the deep repository. This will not lead to a lower priority being given to the subject of corrosion, but the emphasis in the investigations will shift to corrosion in the initial phase, before reducing conditions prevail.

In its comments on RD&D-Programme 95, SKI pointed out that SKB must give an account of the strength properties of the canister under uneven load. As mentioned above, design-basis loads have been studied and check calculations have been made of the strength of the canister under these loads /7-1/. Further investigations will be conducted of the canister's load-bearing capacity and creep properties. The investigations will be complemented by experimental studies on both scale models and full-scale canisters to verify calculated data.

The technology for sealing and nondestructive testing of the canister will be further developed during the coming period. This work will mainly be carried out at the Canister Laboratory, see section 7.6.2.

7.3 Encapsulation and transport to the deep repository

7.3.1 Fabrication of canisters

The empty canisters in which the fuel will be encapsulated will be fabricated in a special canister factory. A preliminary study of how such a factory could be designed is reported in /7-3/. A fundamental principle in the layout that is presented is that the handling of copper and spheroidal graphite iron is separated all the way up until the insert is lifted down into the copper shell.

The copper tubes are fabricated in the factory by roll forming of rolled plate into tube halves, which are subsequently welded together by longitudinal electron beam welding. After welding, the tubes are stress-relieved and machined to the correct dimensions. Copper lids and copper bottoms are machined from forged blanks. The bottoms are then electron-beam-welded to the copper tubes. All welds are tested by both ultrasonic and X-ray (radiographic) inspection.

Stress relieve

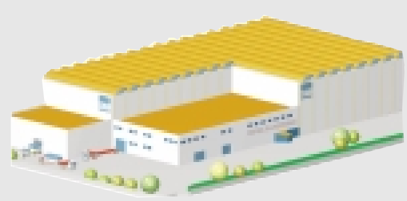
Heat-treat to remove undesirable stresses in the material

Facts

The canister factory, including maintenance shops, offices and inspection laboratory, is estimated to cover 7,000 m^2.

According to rough calculations, the total investment cost will be around SEK 300 million.

The personnel requirement is estimated to be about 30 persons.



Cast and rough-machined inserts of spheroidal graphite iron are delivered to the canister factory for finish machining. Blanks for insert lids are cut out of rolled steel plate and then finish-machined in the factory. After cleaning of all parts, the insert is lifted down into the copper shell. The canister is then finished for delivery to the encapsulation plant.

Where the canister factory will be located has not yet been decided. Questions that must be taken into consideration in siting of the factory concern e.g. shipments to and from the factory and societal aspects, as well as availability of labour and industrial environment. Alternatives to be studied include a siting in the same region as the encapsulation plant or the deep repository, but other alternatives entirely may also be considered.

SKB often receives questions concerning e.g. the availability of copper, fabrication processes, environmental impact and prices. A compilation has therefore been made to provide a total picture of the copper market /7-4/. The quantity of copper that will be consumed when the encapsulation plant is in full operation and produces about 200 canisters per year corresponds to about 1.5 percent of the copper that is consumed in Sweden, or one ten-thousandth of the global production.

7.3.2 Encapsulation plant

To encapsulate the spent nuclear fuel, SKB needs to build an encapsulation plant. In this plant it must be possible to encapsulate all fuel types from the Swedish nuclear power plants. The canisters will be sealed to exacting quality standards and inspected carefully before being transported to the deep repository. High demands will also be made on operational reliability so that canisters can be delivered at the pace required by the deep repository.

The encapsulation plant will be designed so that personnel and the surrounding environment are protected against radiation. The encapsulation process will therefore be carried out by remote control behind heavily radiation-shielded walls. Handling of canisters will also be done by remote control as much as possible. Experience from CLAB and SFR, as well as from other foreign facilities, will be applied in designing the encapsulation plant.

The work of planning and designing the encapsulation plant proceeds in five stages (like the work for the deep repository). In the first stage (phase E), a conceptual design study of the plant is carried out. Then a basic design stage (phase D) is carried out as a basis for an application for a licence to build the encapsulation plant. While the licence application is being processed by the authorities, the general engineering documentation (phase C) needed to begin building the plant is produced. In the next stage (phase B), which proceeds during the time the plant is being built, detailed engineering is carried out. When the encapsulation plant is finished and commissioning is in progress, the design work is concluded by final documentation of the building layout and designs (phase A).

Siting of the encapsulation plant

The encapsulation plant can either be sited at CLAB, at the deep repository, at an existing nuclear installation, or at some other location. It is an advantage if the plant can be coordinated with an existing operation and if radiological competence and experience are available. Other factors that must be taken into account in the siting process are the transfer of spent nuclear fuel, resource utilization, environmental impact and societal aspects.

SKB's main alternative is co-siting of the encapsulation plant with CLAB, since this alternative offers a number of advantages /7-5/. One of the advantages is that the experience of fuel handling possessed by the personnel at CLAB can best be exploited if the encapsulation plant is built on the same site. Furthermore, several of the existing systems and plant sections in CLAB can also be utilized for the encapsulation process. No new land needs to be developed, and no new roads or cooling water plants are needed. Moreover, CLAB and the Oskarshamn Nuclear Power Station provide valuable access to other nuclear resources, such as expertise in radiation protection and handling of radioactive waste.

A co-siting with CLAB is also favourable from a transport point of view, since the transfer of fuel from interim storage to encapsulation does not require any off-site shipments. If the encapsulation plant is not co-sited with CLAB, the fuel first has to be transported in the same way as today from the NPPs to CLAB. The shipments to the deep repository will be simpler if the fuel is encapsulated. The number of shipments will, on the other hand, be greater compared with a siting at the deep repository, since a transport cask with a canister holds fewer fuel assemblies than today's transport casks for unencapsulated fuel. If the encapsulation plant is sited neither at CLAB nor at the deep repository, the transport requirement will be even greater.

Plant design

The design of the encapsulation plant is dependent on where the plant is sited. Since SKB's main alternative is to build the encapsulation plant at CLAB, such a plant is described here. If the plant is sited elsewhere, this design will have to be modified.

The work of designing an encapsulation plant co-sited with CLAB started in 1993 and the main features of this work were presented in RD&D-Programme 95. Since 1995 the encapsulation plant has been further developed and certain modifications have been made. The work being done in the Canister Laboratory will result in additional changes. A detailed description of the presentday design is given in /7-6/. The plant is designed with some flexibility for future changes and extensions. There is also some flexibility if the canister design should be modified in the future.

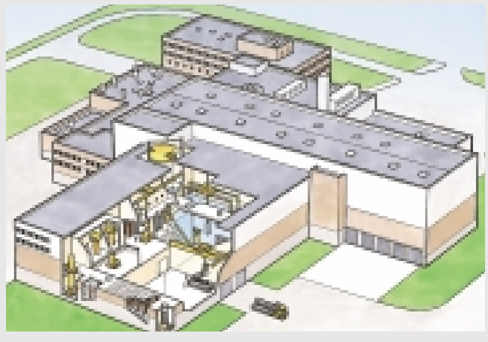
The encapsulation plant consist of an encapsulation building and a store for filled transport casks. The encapsulation building is planned to be built directly adjacent to CLAB's receiving building and to be connected to the fuel elevator which joins the receiving pools with the storage pools. Many of the existing systems in CLAB – such as cooling systems, water purification systems and electrical systems – will be expanded to cover the needs in the encapsulation plant.

Facts

The encapsulation plant is designed with a capacity for processing around 200 canisters with fuel or around 100-200 moulds with core components per year.

The surface area of the plant will be about 65x80 m and the height about 25 m, which is equivalent to the height of the receiving building at CLAB. The total investment cost is around SEK 2 billion.

In addition to the personnel at CLAB, about 40 persons will be required for operation of the plant.



In an initial phase, only spent fuel will be encapsulated, but the plant is prepared to be augmented at a later date with equipment for handling of long-lived LILW (low- and intermediate-level waste). Encapsulation of spent fuel and handling of other waste will take place in separate campaigns.

Safety in operation

Safeguards

System for control and surveillance of fissionable material to prevent unauthorized diversion

To protect personnel and nearby residents, high standards of safety must be met in the operation of the encapsulation plant. The safety standards apply to radiation protection and fire protection, among other things. The spent fuel must always be handled without any risk of criticality. Requirements on safeguards from both Swedish and international competent bodies must be satisfied. The encapsulation plant must meet essentially the same safety requirements as CLAB.

Possible accidents are analyzed during the design work. The encapsulation plant must be designed so that the damage caused by an accident is minimized and does not result in any serious releases of radioactive substances. All lifting devices for fuel and canisters must ensure that handling can be completed to a safe position even if a power failure occurs. Safety in the encapsulation plant is described in greater detail in /7-6/.

Encapsulation process

Encapsulation of the spent fuel is carried out in a number of steps. Figure 7-2 gives an overview of the planned encapsulation process.

Empty canisters are transported from the canister factory to the encapsulation plant in special transport cases which prevent the insert from starting to rust during transport. When the canisters arrive at the encapsulation plant, they are checked thoroughly before being allowed to proceed into the encapsulation process.

Burnup

The total energy released from the nuclear fuel

Decay heat

The heat which spent nuclear fuel emits due to radioactive decay

The existing fuel elevator is used to transport fuel from the storage pools in CLAB to pools in the encapsulation plant. As in CLAB, the purpose of the water in the encapsulation plant is to cool the spent fuel and to shield off its radiation. In the encapsulation plant, the identity of the fuel is first checked with the aid of a camera. Then the assemblies are transloaded and placed in a transport canister with room for twelve BWR assemblies or four PWR assemblies. During transloading the assemblies may pass a measuring station to verify, for example, burnup and decay heat.

When a transport canister is full, it is taken to a bogie situated in the lower position on a ramp in one of the pools. The bogie with the transport canister is moved up the ramp until the transport canister is above the surface of the water. To protect the personnel from radiation, all fuel handling from this point on takes place behind radiation-shielded walls or using radiation-shielded equipment.

At the ramp's upper position, the transport canister is lifted over to a handling cell, see Figure 7-3. In the cell, the transport canister is placed in a drying position where the fuel is dried by hot air. When the fuel is dry, the assemblies are lifted out and placed in a disposal canister which is docked to another part of the cell. The disposal canister is mounted in a shielded frame that is used for moving canisters inside the plant. When the disposal canister is filled a steel lid is bolted onto the insert. The frame is then fetched by a remote-controlled air cushion transporter.

The canister is taken to a station where the void in the insert is evacuated via a valve in the steel lid and subsequently filled with argon. In this way the amount of air remaining in the canister is limited to an acceptable level. The steel lid is leak-tested before the canister leaves the station.

At the next station the canister is docked to a vacuum chamber. The air in the chamber is evacuated so that a vacuum is also created in the gap between the copper canister and the cast insert. The copper lid, which has been transported to the station separately, is placed on the canister and sealed by electron beam welding.

Machining and nondestructive testing of the weld take place in a separate station. Here a visual inspection and some machining of the weld are first done. Then nondestructive testing is performed by means of both X-rays and ultrasound.

The weld is checked by radiographic and ultrasonic testing

If the weld fails nondestructive testing but contains defects that can be repaired, the canister is taken back to the welding station and rewelded. Then the quality of the weld is checked once again. In cases where the weld cannot be repaired by rewelding, the shielded frame with the defective canister is set aside so that regular production is not obstructed. At a convenient opportunity the copper lid is cut off and the canister is returned to the handling cell. There the fuel is transferred to an empty transport canister standing in one of the drying positions. The canister is decontaminated and sent to recycling, while the unloaded fuel assemblies in the handling cell are transferred to a new canister.

When a canister passes nondestructive testing, the weld is finish-machined. Then the canister is taken to a position where it is lifted out of the shielded frame and transferred to the next station. This lift is made with a special canister handling machine, which is also used for placing empty canisters in shielded frames. In this station, the canister is checked for contamination by performing smear tests on the outside of the canister. The station is equipped with high-pressure water spray nozzles, which are used if the canister should need to be decontaminated.

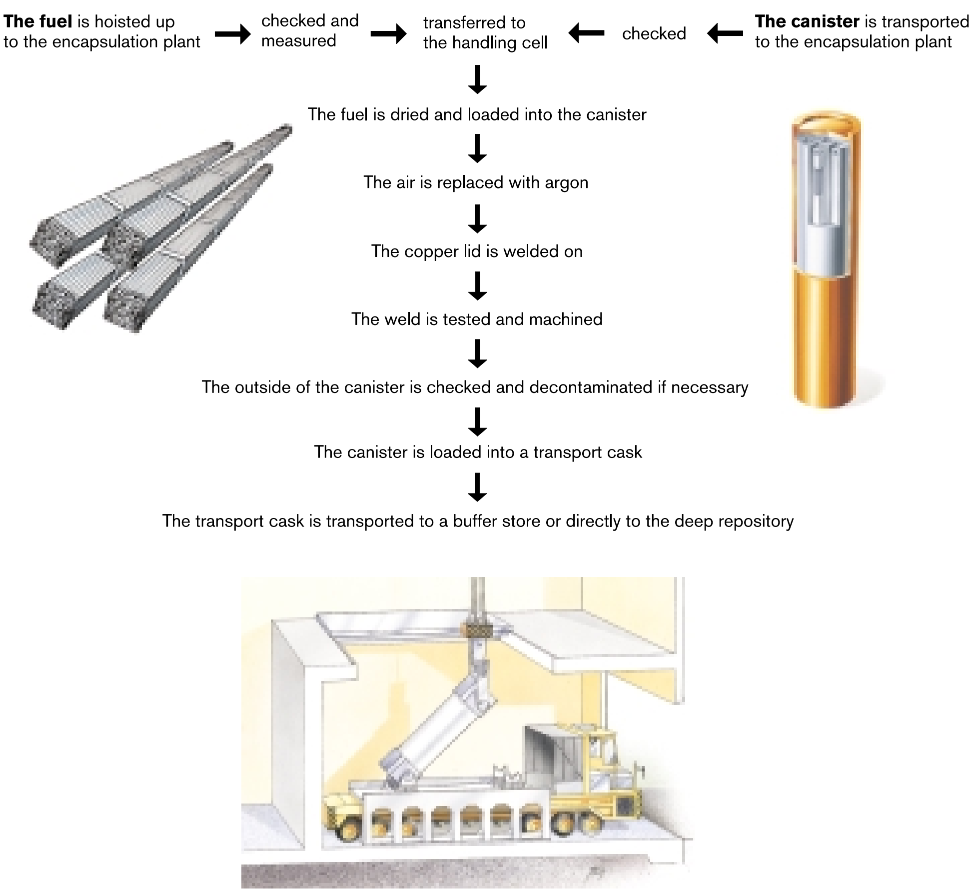


***Figure 7-2.** The different steps in the process for encapsulation of spent nuclear fuel.*

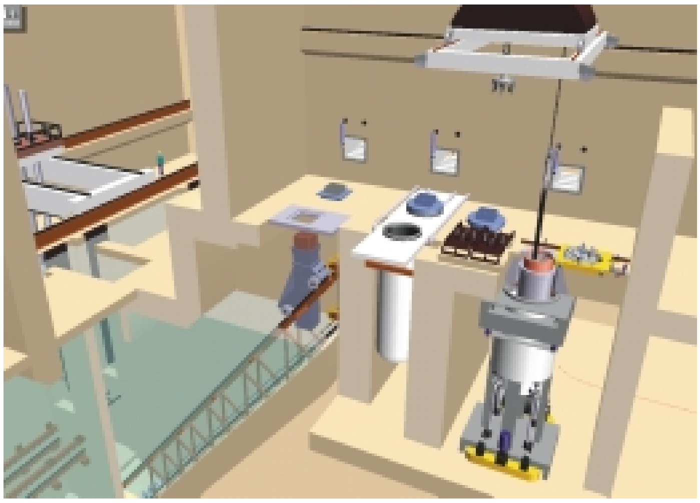


Figure 7-3. *The fuel is brought via a ramp to the handling cell, where the fuel is dried and transferred to a disposal canister.*

In the final operation in the encapsulation building, the canister is lifted over to a transport cask. The canister is lowered into the cask, which is then fitted with a lid. The filled transport cask is lifted by means of an overhead crane to a transport frame located in a transport air lock. The cask is transported out of the plant by means of a specially-built vehicle. Similar handling of transport casks is done routinely today in CLAB. From the encapsulation building, the canister is taken directly to the deep repository or to a store for filled transport casks.

7.3.3 Buffer storage of filled canisters

Inside the fenced-in area for CLAB and the encapsulation plant, SKB plans to build a buffer store where transport casks with finished canisters can be kept while awaiting delivery to the deep repository. The buffer store will be built in sections, where each section consists of a concrete slab in a building that holds about ten transport casks. Building in sections makes it possible to expand storage capacity as needed.

Buffer storage of canisters can also take place in a similar store at the deep repository. This provides greater flexibility and reduces the risk of disruptions if deliveries of canisters are delayed. The number of transport casks that need to be accommodated in the two stores depends on where the deep repository and the encapsulation plant are sited.

7.3.4 Transport to the deep repository

The transportation system that is required to transfer canisters with fuel from the encapsulation plant to the deep repository will be based on the same principles as today's system for shipments from the NPPs to CLAB. To satisfy the very tough safety requirements that are made, the canisters will be transported in special transport casks. The main purpose of the casks is to shield off the ionizing radiation from the fuel. The transport casks can thereby be handled by the personnel without any extra radiation protection measures. The levels on the outside of vehicles and railway cars are so low that they have no effect on passers-by.

Safety against damaging of the canisters is provided primarily by the transport casks, which can withstand, with ample margin, the stresses which can reasonably be expected to arise in the event of an accident, even a serious one. The transport casks must be approved in accordance with the international requirements made in the IAEA's transport recommendations. From a safety point of view, no protective measures are needed for nearby residents when the canisters are transported to the deep repository. Safety during transport to the repository is examined more closely in /7-7/.

The long experience that exists of transporting radioactive waste – both in Sweden and abroad – will be drawn on in designing the future transportation system for encapsulated fuel. Compared with today's shipments to CLAB, handling in connection with transport to the deep repository will be simpler since the fuel will then be encapsulated in leaktight canisters. Moreover, the radiation from the fuel has declined considerably during interim storage in CLAB.

Shipments to the deep repository can take place by sea or by land. Both railway and highway are possible alternatives for overland transport. Combining the different transport modes may also be considered. How the transportation system is designed will depend on where the deep repository is sited.

7.3.5 Programme for future work

In RD&D-Programme 95, SKB judged that a licence application for the encapsulation plant could be submitted at the turn of the year 1997/98. The phase on which the licence application is to be based has now been completed, but an application will not be submitted until site investigations for the deep repository have been commenced, i.e. not earlier than 2002. For this reason we are planning to prolong this phase.

The encapsulation process will be re-examined to determine if further improvements are possible. Experience from the Canister Laboratory will also be incorporated. Furthermore, we plan to have in-depth studies made of the handling of core components in the encapsulation plant.

During the next few years, SKB will compile supporting documentation for a licence application. The application will include a preliminary safety report and an environmental impact statement. The plant design on which the application will be based will be the result of the aforementioned work.

A large part of the development work during the coming period will be carried out in the Canister Laboratory. The programme for this work is described in section 7.6.2.

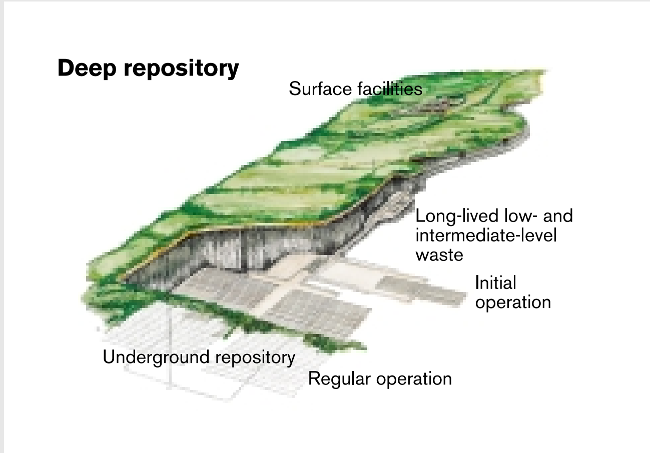
As far as the future canister factory is concerned, SKB will perform more detailed analyses of e.g. plant design, personnel requirements and investment costs during the next few years. The programme for trial fabrication of canisters is described in section 7.6.1.

7.4 Design and development of the deep repository

Design and development of the deep repository involves a step-by-step design process, accompanied by supportive development focused on individual issues or system components which require modification of existing technology or development of new technology. The results of the development work are continuously fed into the design process.

The systematic approach that has been developed for designing the deep repository was presented in the supplement to RD&D-Programme 92 and later in RD&D-Programme 95 as well. A detailed account of the state of knowledge and programme for technical planning and construction of the deep repository was also given in the latter. The contents of the programme still apply but the timetable has been revised and adjusted to match the siting process. The current situation regarding design and technology development is summarized in the following.

Facts



Underground

Areas for deposition of encapsulated fuel and other long-lived waste, tunnels and shafts for communication and ventilation.

Depth: 400-700 m
Space requirement: 1-2 km ^{2}
Tunnels: about 15 km for initial operation
about 45 km when completed
Rock volume: about 0.5 mill. m^3 for initial operation
about 1.3 mill. m^3 when completed

Above ground

Goods terminal, buildings for handling of transport casks, bentonite and backfill material, accesses to underground repository, workshops, offices, restaurant and visitors' centre.

Space requirement: 0.1-0.3 km ^{2}
Building volume: about 100,000 m^3

Personnel requirement: about 150 persons in initial operation
about 220 persons in full operation
Cost: about SEK 13 billion, of which about half for construction and initial operation

7.4.1 Design

Design is the process in which the wide-ranging technical planning and development work is brought together and coordinated for subsequent translation into concrete engineering documents for construction and operation. The process includes both facilities and equipment above and below ground, as well as planning of the activities during the construction and operating phases. In the same way as for the encapsulation plant, the deep repository is designed in steps that represent a gradually increasing level of detail. During the course of the work, system studies are conducted to investigate layouts and sub-systems.

The design work should ultimately result in a layout and engineering of the deep repository which:

- enables the deep repository to be built with tried-and-tested technology and good control of execution,
- permits safe and rational operation,
- permits retrieval of canisters, if desired,
- satisfies all established requirements on performance after emplacement and closure.

It follows from these requirements that all aspects of the design process must be closely coordinated with research activities, the safety assessment and the siting work.

Earlier phases of the design work have resulted in a facility description with examples of how the deep repository can be configured /7-8, 7-9, 7-10/. The examples are not tied to any one site, but are rather based on general geological data and other general design premises. They are nevertheless relatively detailed and include all parts of the deep repository above and below ground, as well as different ways to connect the facilities.

The facility description is the first coordinated proposal for the layout of the deep repository and is the platform for the continued design work. Together with other data, it has provided input data for the system analysis with associated study of safety in the operation of the deep repository that is being reported in parallel with RD&D-Programme 98 /7-5, 7-11/. Furthermore, the facility description provides important premises for choosing rock excavation technology, designing machinery and vehicles and developing system solutions for vital functions underground, such as ventilation, rock drainage and electricity supply.

So far the design work has been based almost entirely on general data. This is a consequence of the fact that the siting work is in an early phase. The general siting studies and feasibility studies that have been or are being conducted do not furnish the data on the bedrock that is needed for adapting the underground facilities to local conditions. Data that are needed for site-adapting the surface facilities are more readily available. The feasibility studies have therefore in some cases included sketches of on-surface layouts for specially studied locations. Among other things, the possibilities of joining the deep repository's surface facilities to existing nuclear installations have been studied for Forsmark (Östhammar Municipality) /7-12/ and Studsvik (Nyköping Municipality) /7-13/. This is described more thoroughly in section 6.3.

The layout of the deep repository is based to begin with on general data on the host rock

The next major step in the design work comes when site investigations have commenced. That is when the work of adapting the layout and design of the deep repository to conditions on the site being investigated begins, see Figure 7-4. For each studied site, solutions for sub-systems are combined to form a complete facility. Construction analyses are performed to evaluate the solutions as regards important construction-related factors, possible building methods, resource requirements, etc.

The design work becomes increasingly detailed as data become available from the site investigations. An initial phase is expected to commence roughly one year after the start of site investigations. Then the locations and layout of the surface facility and underground repository will be adapted in rough terms to the characteristics of the site. Connections between the surface and underground portions are also determined (shaft or ramp). Layout drawings of surface facilities, tunnel systems and access ramps/shafts are prepared. In a second phase, starting a couple of years later, drawings and other documents describing both the layout and function of individual facility parts and how the parts are tied together into a whole are produced. The end product is a site-adapted layout and design of the deep repository that is included in the supporting documentation for applications for permits for detailed characterization and construction.

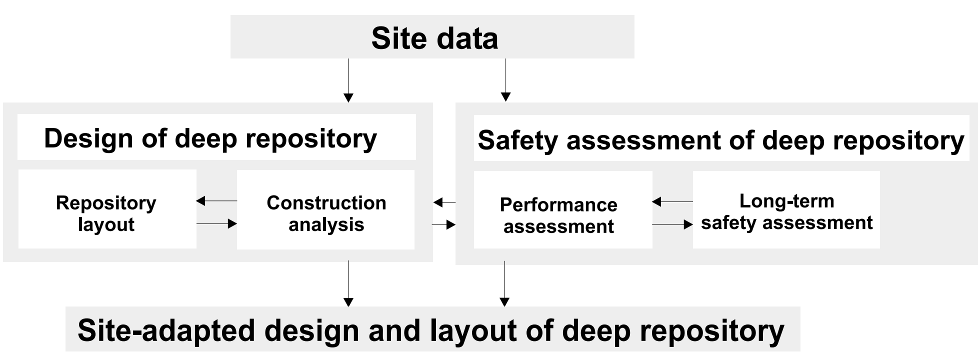


Figure 7-4. *Schematic illustration of links between data from site investigations, design process and safety assessments.*

The deep repository will be adapted to rock conditions on site. Data from site investigations are needed for this

7.4.2 System studies

Alternative disposal methods

In parallel with the development of the KBS-3 method, SKB has studied and evaluated other disposal methods. A comparison was reported in 1992 /7-14/, whereby the KBS-3 method was found to be the most advantageous. The studies of alternative disposal methods have continued, however. One of the alternatives described in 1992 was emplacement in very deep boreholes (several kilometres in depth). To permit better evaluation of this alternative, existing knowledge has been compiled concerning conditions at great depth /7-15/. This is dealt with more thoroughly in Chapter 9.

More technically oriented studies have been performed of variants of the KBS-3 method, and an alternative involving horizontal emplacement in medium-long tunnels (MLH = Medium Long Holes). The variants of the KBS-3 method that have been studied are emplacement of several canisters in the same deposition hole and horizontal deposition holes bored in the tunnel wall. Besides the actual emplacement process, the studies have also covered alternative deposition procedures and the principles for radiation shielding etc. /7-16/. The work has led to the conclusion that radiation shielding which completely encloses the canister is preferable. Another result is that methods for boring or cutting of deposition tunnels with the desired cross-section should be further investigated.

MLH

Medium Long Holes

Disposal method were the canisters are deposited horizontally in small, bored tunnels

FEBEX

Full scale engineering barriers experiment in crystalline host rock

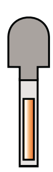
Experiment with simulation of horizontal emplacement at the underground rock laboratory in Grimsel, Switzerland

ENRESA
SKB's counterpart in Spain

The system studies have not changed our previous opinion that the KBS-3 method should remain the main alternative. However, we believe that the MLH method should also be studied further for both technical and economic reasons. A possible advantage of MLH is that deposition is simplified due to the fact that canister and bentonite buffer can be handled as a unit. Compared with KBS-3, however, MLH is based on less tried-and-tested technical solutions. A crucial question is whether canisters can be emplaced and buffer material applied in small horizontal tunnels in such a manner that the desired quality is attained. Other questions concern the method for boring and grouting of the tunnels. A full-scale experiment with emplacement in a bored tunnel (FEBEX) is under way at the underground research laboratory in Grimsel, Switzerland /7-17/. The experiment is being conducted in international cooperation and under the leadership of ENRESA of Spain. SKB is participating in the work and we will follow the experiment as a part of the development of the MLH method.

In its statement of comment on RD&D-Programme 95, SKI said that the MLH method and related machine development should be tested at the Äspö HRL. SKB shares this opinion, but believes that results of ongoing investigations, the FEBEX experiment in Grimsel and planned experiments with vertical deposition at Äspö should be awaited before a decision is made to test the MLH method on a full scale.

Repository in two levels

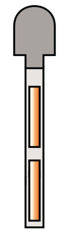


KBS-3
The main alternative

The possibility of adopting a two-level repository layout, with a vertical distance of 100 metres between the levels, was studied in the early 1980s. A two-level layout would reduce the horizontal extent of the repository, which could increase flexibility in siting and layout. The concept also has disadvantages. It may, for example, be more difficult to arrange rational operational communications, and certain functions may need to be duplicated.

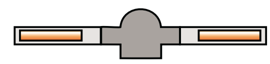
Two-level layouts have since been used for sample calculations in ongoing safety assessments (SR 97). The thermomechanical aspects of such a layout have also been analyzed /7-18/. In line with an ambition to examine a broad range of options for a site-adapted configuration of the deep repository, the judgement is that the two-level alternative should also be further studied. SKI also pointed out in its review of RD&D-Programme 95 that they desired to see a renewed investigation and a comparison with a single-level repository.

7.4.3 Technology development



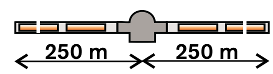
KBS-3
Deposition of several canisters

Construction, operation and closure of the deep repository can largely be done using technology that is known and proven from other fields. The required knowledge can largely be taken from the nuclear industry, underground construction, and conventional civil engineering. Nevertheless, due to the special requirements that are made on the deep repository and the unique nature of some of the activities there, considerable work is needed to adapt existing – or, in some cases, develop new – technology. This development work relates to a number of technical areas and includes everything from calculations and investigations to experiments where system components are subjected to full-scale trials.



KBS-3
Deposition in horizontal holes

The goals and scope of SKB's technology development efforts were described in RD&D-Programme 95. In general it can be said that the emphasis has gradually shifted from theory, calculations and experiments on a small scale towards testing and demonstration of system parts on a full scale. An important step in this direction is being taken now with the experiments and demonstration activities that are planned at the Äspö HRL. These entail an integration of studies of safety and performance of system parts with testing and demonstration of technology and practical execution. The programme for full-scale testing is presented in section 7.6.



Medium Long Holes (MLH)

An overview of important technical questions that are the subject of development efforts is shown in Table 7-1. The current status of development work pertaining to construction, operation and closure of the deep repository is described in the following. Possible retrieval of canisters is dealt with in section 7.5.

Underground construction

Tunnel boring

TBM
Tunnel boring machine

The tunnels in the deep repository can be excavated using either conventional methods (blasting) or by full-face boring using a tunnel boring machine (TBM). Evaluation and choice of tunnelling method for the tunnel types and ramps in the deep repository will be done at a relatively late stage. Conventional drill-and-blast technology is available for all tunnel types and ramps. Technology for boring tunnels and ramps is also available, but machines available on the market are intended for boring single, long tunnels. Some further development and modification of the technology is required for boring many, short tunnels, as will be done in the deep repository.

ZEDEX
Zone of excavation disturbance experiment
Research project at the Äspö HRL to study damage in tunnel walls caused by boring and blasting of tunnels

The ZEDEX experiment at the Äspö HRL has been completed and the results reported /7-19/. The primary purpose of this experiment was to compare the mechanical damage in the tunnel walls caused by blasting as compared with boring. The experiment yielded important quantitative information on the

Table 7-1. Important technical questions for different phases of the deep disposal project

Underground construction	Boring of tunnels (TBM) Boring of deposition holes Grouting of rock Detailed rock characterization during tunnelling
Operation	Fabrication of bentonite blocks Deposition of canisters and buffer material Backfilling and sealing of deposition tunnels
Closure	Backfilling of tunnels, shafts and ramps Permanent sealing of tunnels (plugs) Sealing of boreholes
Retrieval	Freeing and removal of canisters

damage pattern for the two tunnelling methods, as well as different variants of blasting. As expected, boring produced much less damage around the tunnel than blasting.

Boring of deposition holes

Posiva

SKB's counterpart in Finland

The technology that will be used for boring deposition holes is basically the same as that used for boring horizontal tunnels. Boring downward is, however, an unusual application and requires modification and testing of the technology. An initial test on a near-full scale was carried out a couple of years ago in Olkiluoto, Finland, in collaboration with Posiva /7-20/. The boring in Olkiluoto has also been used to develop methods for quantitatively describing the zone around the borehole where the rock is mechanically disturbed by boring /7-21/.

At present, full-scale boring of around ten deposition holes is planned at the Äspö HRL. The goal of the boring programme is to evaluate and further develop the boring technique as such, as well as to make the deposition holes that are needed for planned full-scale experiments and demonstration activities. This is dealt with more thoroughly in section 7.6.

Grouting

Grouting

Sealing of fractures in rock by injection of a grout, usually a cement slurry, to prevent water from leaking into tunnels

The safety of the deep repository does not presuppose any measures to seal the rock or otherwise alter is properties. During construction and operation of the deep repository, on the other hand, it is important to control the inflow of groundwater. SKB has therefore been conducting active development work on grouting of water-bearing structures in conjunction with rock excavation. The work has been expanded since RD&D-Programme 95 was presented, and a project organization with research resources from universities and other expertise has been established /7-22/.

An important purpose of the ongoing development work is to increase our understanding of the grouting process and how the results are dependent on the properties of the grouts and the rock. This is essential for being able to choose a grouting method and make reliable predictions of the grouting results, based on data from rock investigations. We are particularly studying grouting under the conditions that can be expected to prevail in the deep repository as far as rock quality and water pressure are concerned. Another purpose of the ongoing work is to broaden and deepen our knowledge of the durability of the grouts and their possible effects on the chemical conditions in the deep repository. The importance of achieving a better understanding of these factors was particularly emphasized in SKI's review of RD&D-Programme 95.

Theoretical and experimental studies of, among other things, the flow properties of the grouts have improved our understanding of the grouting process in a rock mass /7-23/. Follow-up of the grouting work has shown that the grouting process can be described relatively accurately. A good bank of field data has also been accumulated /7-24, 7-25/. However, the knowledge is still insufficient when it comes to translating experience from one geological environment to another.

Operation

Fabrication of bentonite blocks

Highly compacted bentonite in the form of blocks will be used as a buffer around the canister. Another use for bentonite blocks is as components in plugs for sealing of tunnels. There are primarily two methods available for fabrication of bentonite blocks: isostatic pressing and uniaxial pressing /7-26, 7-27, 7-28/. Both methods are being further developed and tested by SKB. The purpose is to develop methods and equipment capable of producing the blocks needed in the deep repository on an industrial scale.

The advantage of isostatic pressing is that even big blocks are homogeneous. The disadvantage is that machining is probably required after compaction. Equipment is not available today in Sweden that is capable of isostatic pressing of blocks of the size required in a deposition hole. Tests have, however, been done on a smaller scale (approximately 1:4). The results are good in terms of both quality and finish-machining of the blocks to the desired dimensions.

With uniaxial pressing, press equipment originally intended for other purposes can be used for experimental full-scale fabrication of bentonite blocks. A disadvantage of uniaxial pressing is that the blocks may be inhomogeneous. Tests have shown that this problem can be solved, however. Both large and small blocks have been made by uniaxial pressing. This method will be used for fabrication of the more than 100 blocks that are needed for the planned experiments at the Äspö HRL, see section 7.6. A press mould for this has been made, and an experimental series of more than ten blocks has been produced for fine adjustment of the fabrication process. Figure 7-5 shows one of the blocks.

The conclusion of the development work to date is that both isostatic and uniaxial pressing can be used for compaction of blocks for the buffer around the canisters. For other blocks, uniaxial pressing is the best method.

Isostatic pressing

The material is subjected to equal pressure in all directions

Uniaxial pressing

The material is subjected to pressure in one direction

An experimental series of full-sized bentonite blocks is fabricated

Emplacement of canister and buffer material

The deposition (emplacement) of the canister and the bentonite blocks that will comprise the surrounding buffer comprises a chain of operations where high demands are made on both reliability of execution and the end result. Development of both deposition equipment and execution of the deposition sequence is needed.

The steps in the planned deposition sequence are as follows:

- Inspection, documentation etc. of the deposition hole and preparation by bottom levelling.
- Application of solid bentonite blocks as a bottom pad under the canister and ring-shaped blocks that will surround the canister.
- Deposition of the canister.
- Application of bentonite blocks on top of the canister (overpack).
- Backfilling with bentonite and gravel up to tunnel level.

Figure 7-5. *Ring-shaped bentonite block on a full scale (outside diameter 1.65 m, height 0.5 m) fabricated by uniaxial pressing. Blocks of this type will be used for the full-scale trials at the Äspö HRL.*

Deposition in radiationprotected environment

The process of canister deposition must be carried out in a radiation-shielded environment. We have studied different principles for this and decided that the canister must be completely surrounded by a radiation shield until the deposition process is finished. The radiation shield can then be parked above the deposition hole and moved only after the canister has been deposited and covered with bentonite blocks that shield off radiation. An important question is what bentonite thickness is needed on top of the canister to enable work to be carried out in the tunnel without danger from radiation. Calculations show that an approximately 50 cm thick overpack of highly compacted bentonite provides adequate radiation protection under normal conditions.

Water ratio

Weight ratio between water that evaporates from the material at a temperature of 105°C and the remaining dry material

The process of water saturation of the bentonite blocks, as well as the density achieved after water saturation, are essential parameters for proper buffer function. These parameters can be affected during the deposition process. There are, for example, different alternatives as regards the initial water ratio in the blocks. An initially elevated water ratio facilitates heat conduction through the buffer after emplacement. The lower density obtained can be compensated for by filling the gap between the bentonite blocks and the rock with pellets of bentonite. Different methods for this are being studied. Tests have shown that it is practically feasible to fabricate blocks with an elevated water ratio.

Another measure that can improve heat conduction in the initial phase after emplacement is to fill the gaps between canister and bentonite blocks, and between blocks and rock, with water. For this and other reasons, various ways to artificially inject water into the gaps are being studied.

The development work regarding vehicles and other equipment for deposition has been intensified. At present a full-scale prototype of the deposition machine is being manufactured. This is described more thoroughly in section 7.6.

Backfilling and sealing of deposition tunnels

Backfilling of the deposition tunnels is planned to be done with layers of backfill material that are compacted in-situ. The purpose of the development work currently in progress is to develop materials and practical methods for application that meet the mechanical, chemical and hydraulic requirements made on the backfill.

Different materials for backfilling the tunnels are tested

Different materials have been developed and tested in the laboratory /7-29/. Mixtures of bentonite and crushed rock, or bentonite and quartz sand, have proved to meet the requirements. The suitable material composition is greatly affected by external conditions, and the salinity of the groundwater is an important parameter. Increased salinity necessitates a higher bentonite fraction in order for the material to have the desired swelling properties. Another possibility being studied is to use only crushed rock as a backfill material, possibly in combination with permanent tunnel seals that limit water flow along the tunnels after emplacement.

Initial field tests with mixing, backfilling and compaction in tunnels have been conducted at the Äspö HRL. Examples of practical aspects that have been studied are different methods for compaction and special measures required for backfilling nearest the tunnel roof. Additional field tests are planned, see section 7.6.

Concrete structures for temporary sealing of backfilled deposition tunnels are developed

After backfilling, the deposition tunnels will be temporarily sealed with plugs so that they are separated from the adjoining transport tunnel. The seals must be designed so that they are sufficiently watertight and are able to resist the water and swelling pressure generated in the backfill. Tunnel seals of concrete are known technology, so SKB is studying different concrete structures for the deposition tunnels. The transition between seal and rock is an important part of the seal. In a blasted tunnel, the blast-damaged zone around the tunnel must also be sealed, which can be achieved by having the seal fit into a slot in the rock wall. Tests at Stripa have shown that a good seal between rock and concrete can be obtained by means of an "O-ring" of bentonite /7-30, 7-31/. The influence which the seals can have on groundwater conditions and the chemical environment in the long term is of subordinate importance, since they can be removed later on.

Sealing

Permanent plugs

Permanent seals that cover the entire tunnel profile may be needed to reduce groundwater flow in and around backfilled tunnels and shafts. Seals may also be needed to isolate fracture zones that intersect deposition tunnels.

Plugs may be used to permanently seal tunnels and shafts.

Permanent seals in the form of plugs have been analyzed in several studies with regard to effects on groundwater flow and rock-mechanical aspects /7-32, 7-33, 7-34/. Plug performance has been evaluated for a number of different assumptions regarding the hydraulic properties of the tunnel backfill and the disturbed zone. Possible designs of plugs have also been studied.

Possible designs are being studied, but the need will not be determined until data is available from site investigations

Two main questions remain to be answered, namely to determine:

- whether permanent plugs are needed at all, and if so how many. This question should wait until criteria for water flows have been determined and site-specific data are available,
- how permanent plugs are to be designed. The most important questions here are to determine which materials can be permitted in the plugs and how previously built temporary seals of deposition tunnels can be used, in whole or in part.

Sealing of boreholes

In site investigations and detailed characterization, as well as during the construction phase, a large number of holes will be drilled to investigate the rock around the deep repository. On closure, the holes must be sealed permanently to prevent water transport.

The purpose of ongoing technology development is to devise rational and effective methods for sealing boreholes drilled from the ground surface or from tunnels. The main plan is to carry on with the technology developed at Stripa. Tests were conducted there with seals based on bentonite plugs /7-35/.

7.4.4 Programme for future work

Design procedure

The integrated programme for designing the deep repository is adapted to the siting activities. With the planned start of site investigations in just over three years, this means that activities during the coming three-year period will be based on existing facility descriptions and general bedrock data. The material we compile should be broad enough that the different technical solutions that may, according to local conditions, be appropriate in the site-specific phase have been sufficiently perfected when this phase begins.

During the coming three years, special investigation initiatives are planned when it comes to:

- deposition methods,
- design of underground excavations (tunnels, rock caverns, shafts, ramps),

- relative location of access shafts/ramps and sections underground, plus relative location of tunnels and deposition holes,
- factors governing design, construction technology and deposition technology.

In a six-year perspective, we believe that the site investigations have made good progress and that an initial phase of site-specific design has begun. Certain technical sub-systems will have to be chosen in the initial phase of the site-specific phase. This includes type of access (ramp or shaft), transportation system and tunnelling methods.

Within a six-year period, the site investigations are expected to provide data that permits a preliminary site-specific layout of the deep repository

When solutions-in-principle for these sub-systems have been determined, the design work is dependent on the geoscientific data obtained from the site investigations. The background data that can be expected to exist within a six-year period will be used to devise a rough, site-specific layout of the deep repository. This means that the location, peripheral boundaries and layout of the surface facilities will be stipulated preliminarily. Underground facility sections will be positioned preliminarily and delimited with respect to the onsite geology, particularly in relation to the locations of major deformation zones.

Alternatives for deposition

The studies of alternative deposition methods continue

The alternative deposition methods which we have identified (see 7.4.2) will be evaluated during the coming three-year period. The relatively unproven technical solutions included in the MLH method will be subjected to further study. Depending on the results of these studies, tests of horizontal emplacement at the Äspö HRL can be considered. The two-level repository concept will be further refined to a level of detail that corresponds to the background data for site-specific design.

Technology development

Development and engineering of machinery and vehicles will be a primary task during the next few years. The Äspö HRL is the base for most machine development. The programme for full-scale testing of technology for construction and operation entails:

- boring of a number of deposition holes,
- manufacture and testing of a prototype of a deposition machine,
- testing of the deposition sequence,
- testing of the backfilling method.

The planning of these activities is described in section 7.6.

In parallel with technology testing at the Äspö HRL, we will continue the development work within the areas described in section 7.4.3. Advances in the technology for boring of tunnels will continue to be monitored. This includes both improvements in machinery and experience from applications.

Grouting

Continued technology development for

- Grouting
- Fabrication of bentonite blocks
- Sealing of tunnels and boreholes

In the field of rock grouting, we plan during the coming three-year period to continue our studies of models that describe the rock from a grouting view-point and simulate the grouting process. We also intend to develop a hydraulic testing method for field testing of rock mass grouting properties. Furthermore, investigations are planned of the flow properties, sealing capacity and durability of different grouts. Most of the experimental studies will be done in a laboratory. Towards the end of the three-year period, a major verifying field test is planned at the Äspö HRL. The environmental properties of the grouts will be explored before they are used.

Fabrication of bentonite blocks

The technology for fabrication of bentonite blocks will be further developed. During the next three years we plan to:

- fabricate the blocks that are needed for the tests at the Äspö HRL (uniaxial pressing),
- continue the development of technology for isostatic pressing,
- compare the methods uniaxial and isostatic pressing, technically and economically,
- continue the evaluation of the importance of bentonite quality and pretreatment methods for the quality and performance of the blocks.

Sealing of tunnels and boreholes

Tunnel seals in the form of plugs of the type planned to temporarily seal deposition tunnels will be included in several of the full-scale experiments at the Äspö HRL. Data from the experiments will be used to analyze the hydraulic and mechanical performance of the plugs. With this as a basis, the proposals for engineering and execution of plugs and sealing between plug and surrounding rock will be further refined. The work will be pursued campaign-wise during the coming six-year period. Interim results are expected to be obtained in about three years.

The need for permanent seals cannot be determined until criteria for flows have been established and data from site investigations are available. Pending this, we will investigate the general prospects of using cast plugs as permanent seals. Quantities and types of concrete that can be permitted with a view towards the chemical conditions in the repository are an important factor. Further, we plan investigations to increase our understanding of the complex mechanical behaviour of the rock-backfill-plug system. Besides the material properties of the system components, both instantaneous and time-dependent loads and deformations must be taken into consideration.

Further refinement of the technology for sealing boreholes also includes both material selection and practical execution. Field tests at the Äspö HRL are planned during the period. Within a six-year period we plan to further refine existing technology for short holes (a few hundred metres) for applications in deep investigation holes (up to about 1,000 metres).

7.5 Possible retrieval of deposited canisters

The canisters can be retrieved from the deep repository

The deep repository will be designed so that it is possible to retrieve previously deposited canisters. However, this requirement must not lead to a degradation of the long-term performance of the repository. Retrieval may become desirable for all 400 or so canisters in the initial stage of the deep repository if another method for disposing of or making use of nuclear fuel should be preferred in the future. The retrieved canisters must be able to be stored temporarily in a special facility. It may also be necessary to take up an individual canister from a deposition hole if one of the safety requirements is not met.

7.5.1 Retrieval from the deep repository

Before the bentonite clay in the deposition hole has been saturated with water and swollen, the canister can be taken up to the deposition tunnel without the bentonite having to be removed. If the bentonite has become saturated with water, the canister must first be freed from the bentonite in order to be retrieved.

A deposited canister can be freed

- mechanically (the bentonite is drilled away)
- hydrodynamically (the bentonite is flushed away)
- thermally (a temperature change causes a change in volume)
- electrically (water is conducted up to the canister electrically)

SKB has evaluated four different methods for freeing a canister: mechanical, hydrodynamic, thermal and electrical. A description, evaluation and comparison of these methods is given in /7-36/. The methods of freeing are in varying degrees dependent on knowledge of the canister's position in the deposition hole.

In developing technology that can be used to determine the position of the canister in the deposition hole, we have so far studied mechanical, electro-magnetic, thermal and acoustic methods. None of these methods is judged to be suitable for a detailed determination of the canister's position in an un-opened deposition hole. It is, however, believed that acoustic and electro-magnetic methods can be used when the distance to the canister is small. Due to difficulties in accurately detecting the position of the canister, the future development work should focus on a retrieval method that doesn't require such exact position determination.

The work we have done so far seems to indicate that one hydrodynamic and one thermal method have potential for further development for use in freeing a canister in the deep repository. The hydrodynamic method involves first loosening up the upper part of the bentonite with salt water, after which the loosened layer is pumped away from the hole. In the thermal method, the bentonite is cooled so that it shrinks. This causes a gap to form around the canister, enabling the canister to be removed.

7.5.2 Transport of retrieved canisters

After being freed, the canister can be lifted into a radiation shield and transported up to ground level in the same type of transport cask as that used for transporting canisters to the deep repository. If the canisters have to be transported away from the deep repository site, this can be done by the system that is used for transport to the deep repository.

7.5.3 Buffer storage of canisters

Retrieved canisters can be placed in a buffer store

In the event of retrieval of canisters from the deep repository, there may be a need for buffer storage of up to 400 canisters. If that many canisters need to be buffer-stored, it is not appropriate to store them in the same way as at the encapsulation plant. Instead, the canisters would probably be placed upright in a radiation-shielded store, see Figure 7-6.

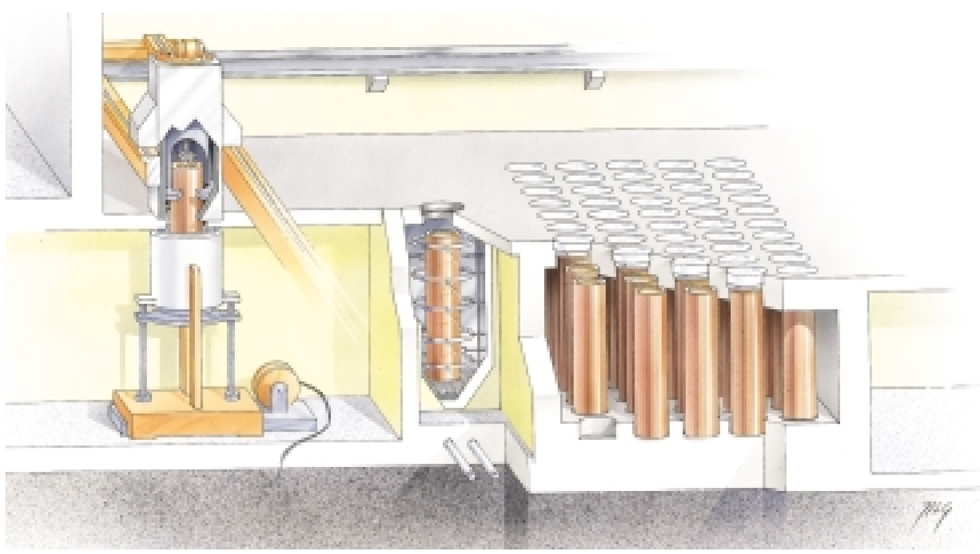


Figure 7-6. *An example of a buffer store for retrieved canisters.*

Above each storage position is a plug that is lifted aside when a canister is to be lowered down into or lifted up out of a position. The canisters and the plugs are handled by remote control with a radiation-shielded handling machine. Next to the buffer store is a station where the retrieved canisters can be checked and cleaned to remove any adhering bentonite clay. The canisters are cooled by air in a self-circulating ventilation system.

A buffer store for retrieved canisters can either be built in a rock cavern or in a building at ground level. The buffer store can be located at the deep repository, at the encapsulation plant or some other place.

7.5.4 Programme for future work

SKB plans to further refine the technology for retrieving deposited canisters during the coming three-year period. The development work will be carried out in steps that partially overlap:

- Development of equipment and method.
- Demonstration on a full scale (at Äspö HRL).
- Development of a method that can be used in the deep repository.
- Design of a buffer store for retrieved canisters.

The part of the programme that involves full-scale testing of the method is described in greater detail in section 7.6.6.

7.6 Full-scale testing of technology

SKB has trial-fabricated canisters on a full scale

A central part of SKB's work in the years to come is to develop, test and demonstrate the different parts of the deep disposal system on a full scale and under realistic conditions. The tests will include the most important steps in fabrication and sealing of canisters as well as construction, operation and closure/sealing of the deep repository. Some tests, for example trial fabrication of canisters on a full scale, have already been going on for several years. SKB plans to expand the activities for development and testing of full-scale technology during the coming years. The majority of the tests will be performed at the Äspö HRL and the Canister Laboratory.

In addition to the technical aspects of the full-scale tests, it is important to be able to practically demonstrate the various steps in encapsulation, transport, emplacement and retrieval to both specialists and the general public. Demonstration of emplacement and retrieval will therefore be carried out at the Äspö HRL.

7.6.1 Trial fabrication of canisters

In the past few years, fabrication trials with copper canisters and cast inserts have been conducted on a full scale in accordance with the programme described in RD&D-Programme 95, see Figure 7-7. The results are reported in /7-37/. The results of the fabrication tests during 1994 and 1995 are presented in /7-38/. The detailed canister design was slightly different then, but the basic concept was the same as today.

Trial fabrication of copper components

Roll forming

Forming of plate into tube halves

To date, SKB has fabricated copper tubes on a full scale using three different methods: roll forming of tube halves that are welded together by electron beam welding, extrusion and pierce and draw processing. Other conceivable methods

Figure 7-7. *Finished parts from trial fabrication of canisters.*

Extrusion

Squeezing seamless tubes through a die in one step

Pierce and draw processing

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

Hot isostatic pressing

Compression moulding of powder under high pressure and high temperature

Electrodeposition

Electrochemical process whereby a metallic layer is built up on a surface

Spray forming

Powder-metallurgical method for direct transfer of molten metal to a solid body

for fabrication of copper tubes are hot isostatic pressing (HIP), electrodeposition and spray forming.

During 1996 and 1997, six copper tubes were trial-fabricated on a full scale by roll forming of rolled copper plate to tube halves which were then welded together by electron beam welding. The disadvantage of roll forming is that there are two long welds along the entire copper tube. Lids and bottoms for the six tubes were machined from preformed forged blanks.

The first attempts to fabricate seamless copper tubes by extrusion were reported in RD&D-Programme 95. The trials showed that extrusion is probably a feasible alternative, even though the structure of the copper material was too coarse-grained. Our opinion is that this problem can be solved by changed parameters in extrusion. To find out more about how the process parameters influence the microstructure in extrusion of copper, research projects are currently under way in cooperation with KTH (the Royal Institute of Technology) and the Institute of Metals Research in Stockholm. The results of these studies will serve as a basis for the new full-scale extrusion trials that will be conducted in 1998.

Pierce and draw processing is another method for the fabrication of seamless tubes. The method involves piercing a billet with a mandrel and then drawing the billet stepwise over mandrels to the desired diameter. Today this method is used for industrial fabrication of steel tubes in diameters that correspond to those of the canisters. Experience of fabricating copper tubes using this method is very limited, however. SKB has therefore recently conducted an initial trial which showed that it is possible to form copper tubes to the desired dimensions on a piercing mill /7-37/. New trials will be conducted during 1998 and 1999 to further investigate whether it is possible to fabricate copper tubes with the specified microstructure and permissible dimensional tolerances.

The main alternatives for fabrication of copper tubes to canisters today are roll forming and seamless tube fabrication, but other methods have continued to be, and will continue to be, evaluated. Laboratory-scale tests of hot isostatic pressing and electrodeposition are under way and will be evaluated during 1998. The results will determine whether it is worthwhile continuing to work with these methods. The feasibility of fabricating copper canisters by spray forming has been explored, but due to difficulties with pore formation we have decided to discontinue working with this method for the time being.

Trial fabrication of cast inserts

In recent years, cast inserts have been trial-fabricated in both cast steel and spheroidal graphite (nodular) iron at several different foundries. One insert of half length and one of full length have been fabricated in cast steel (SS 14 13 06), while five whole inserts have been cast in spheroidal graphite iron (SS 14 07 17). The channels for the fuel assemblies were formed by square steel sections welded together into a cassette and placed in a mould, see Figure 7-8. The space between the cassette and the mould is then filled with molten iron, see Figure 7-9.

The trial castings have shown that spheroidal graphite iron has a number of advantages compared with cast steel /7-37/. The risk of defects is lower since spheroidal graphite iron has better castability. This also means that the inserts can be cast with an integral bottom, which is not possible if cast steel is used. Furthermore, cast steel is considerably more expensive, due to, for example, lower material yield and the need for heat treatment. At the present time, spheroidal graphite iron is therefore the only material being considered for the cast insert.

Quality assurance

A quality manual for canister fabrication was compiled during 1997. The requirements made in this manual correspond to the requirements of ISO 9001. The quality system for canister fabrication will cover the entire chain from material suppliers to delivery of finished canisters.

Figure 7-8. *A welded cassette for BWR fuel is placed in the mould.*

Figure 7-9. *The mould is filled with molten iron.*

Programme for future work

The overriding objective for the next three years when it comes to trial fabrication of canisters is to be able to choose methods for fabrication of all parts of the canister. The entire fabrication chain will then have been tested and specified with a certified quality assurance system when it is time to apply for a licence for the encapsulation plant.

Two complete canisters for BWR fuel will be fabricated in 1998 for projects at the Äspö HRL, and an additional six or seven canisters in 1999 for the same purpose. In addition to these canisters, copper tubes and copper lids will be fabricated and delivered to the Canister Laboratory.

All parts of the canisters will be fabricated to such an extent that different fabrication methods can be tried out and optimized. Furthermore, parts need to be fabricated in sufficient quantities to test and qualify both nondestructive and destructive testing methods.

In conjunction with trial fabrication, a survey and assessment of available suppliers will be carried out. The purpose of this is to forge long-term relations and find the best suppliers for the future.

ISO 9001
International quality standard

The quality system for canister fabrication will be progressively implemented and improved over the next few years. Important areas for further work are methods and specifications for nondestructive testing, procedures for document management and systematic quality audits of suppliers. The objec-tive of this work is an approved certification according to ISO 9001.

7.6.2 The Canister Laboratory

In RD&D-Programme 95, SKB considered having a laboratory for encapsulation technology (then called a pilot plant) built to develop the central parts of the encapsulation process. We have now built such a laboratory in Oskarshamn, see Figure 7-10. The Canister Laboratory is being put into operation in the autumn of 1998.

The Canister Laboratory will serve as a centre for development of encapsulation technology and training of personnel for the encapsulation plant. The main purpose is to test equipment for sealing and inspection of canisters. This is needed to provide a good basis for the continued planning and design of the encapsulation plant. In the Canister Laboratory, SKB will demonstrate that canisters can be sealed with the requisite quality at the production rate that will be required in the encapsulation plant. The results from the Canister Laboratory will comprise an important part of the application for a licence for the encapsulation plant.

The Canister Laboratory

will be a centre for

- development of encapsulation technology
- training of personnel

Figure 7-10. *The Canister Laboratory in Oskarshamn.*

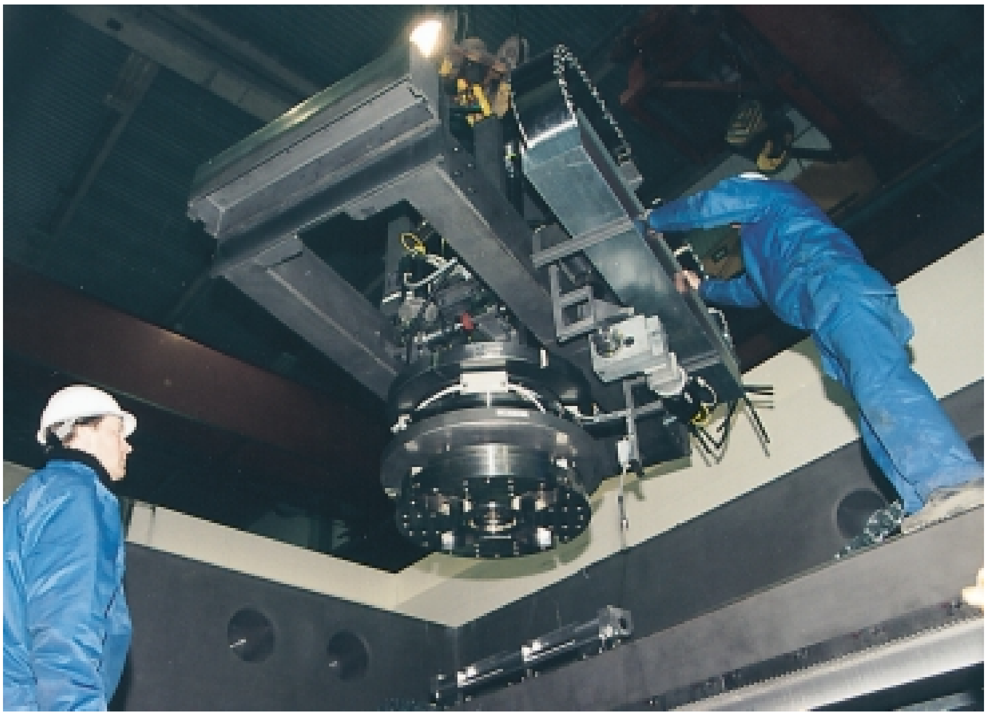


Figure 7-11. *Installation of equipment in the Canister Laboratory's welding station.*

The overriding objective of the work in the Canister Laboratory is to verify the performance and availability of the equipment and to determine processing times and capacities. Operating and maintenance instructions will then be prepared prior to assembly and commissioning of equipment in the encapsulation plant. The work includes taking the necessary steps to correct malfunctions and improve equipment and working methods.

The equipment for sealing and inspection of canisters is installed in three different stations: a welding station, a station for nondestructive radiographic (X-ray) testing and a station for nondestructive ultrasonic testing, Figure 7-11. Other important equipment is the canister transport and handling equipment. The equipment that is installed in the Canister Laboratory is designed in basically the same way as the equivalent equipment in the encapsulation plant.

Programme for future work

The programme for the coming three-year period includes series of trial sealings of copper lids. It is estimated that a total of nearly one hundred lids will be welded and inspected during this period.

Important steps in the continued work are to:

- commission the welding equipment to full capacity,
- establish basic parameters for the welding equipment,
- achieve a flawless and controllable welding process,
- establish operational availability and maintenance needs.

The equipment for nondestructive testing will be tried out to make sure it meets the requirements for detection of defects. This is planned to be carried out during the coming three-year period. This will be followed by a period when the methods for nondestructive testing will be qualified, which can take place at the same time as licensing of the encapsulation plant.

The Canister Laboratory will also be used for testing and demonstration of other parts of the encapsulation process, such as handling in the encapsulation plant's handling cell. Another important task is the training of operating and maintenance personnel for the encapsulation plant.

7.6.3 Boring of deposition holes

Deposition holes that are 8 m deep and 1.75 m in diameter will be bored at the Äspö HRL

SKB has for many years been working on the development of the method for boring of deposition holes. Important milestones have been the choice of the downward dry full-face boring method and the initial field tests performed in Finland, see section 7.4.3. At present we are planning to bore several deposition holes for full-scale tests and technology demonstration at the Äspö HRL. The diameter of the holes will be 1.75 metres and the depth about 8 metres. Planning of this work has come far, and an initial phase has already been procured. Boring is planned to commence in the autumn of 1998.

During boring, a wide variety of boring parameters will be continuously recorded. With these data as support, the performance of the machine and the peripheral equipment can be studied and optimized. We will also follow up the mechanical effects of the boring procedure on the walls of the holes and other aspects of hole quality. Methods for analysis of the damaged zone have already been developed. Supplementary laboratory tests, as well as field tests, are planned to study the hydraulic characteristics of the system consisting of the bentonite, the rock surface and the damaged zone.

The entire boring programme, including follow-up work, analyses and documentation, is expected to be carried out during the coming three-year period.

7.6.4 Testing of deposition machine

At the Äspö HRL technology for emplacement and retrieval of canisters will be tested

To test and demonstrate the technology for emplacement of canisters in the deep repository, SKB is developing a full-scale prototype of a deposition machine. The purpose of this project is to acquire experience from design, manufacture and operation of such a machine in preparation for the development of a deposition machine for the deep repository. The main goals of the project are to:

- develop and test methodology and equipment for emplacement of canisters,
- demonstrate the various steps in emplacement and retrieval of canisters to both specialists and the general public.

The deposition machine will be put into operation in a tunnel at the 420-metre level in the Äspö HRL. Repeated tests of emplacement and retrieval of canisters are planned in two full-sized deposition holes.

The work of designing the deposition machine was begun in early 1997. The machine is under manufacture and delivery to the Äspö HRL is planned in 1999. The deposition machine is railborne and designed to be used in both blasted and bored deposition tunnels. The design is chosen so that the dimensions of the tunnels are limited, since this is of great importance in the deep repository. Another feature needed in the deep repository is that it should be possible to dismantle, relocate and reassemble the machine in a new tunnel with a reasonable labour input. The machine is radiation-shielded and remote-controlled, but faults can nevertheless be corrected on site. A schematic drawing of the machine is shown in Figure 7-12.

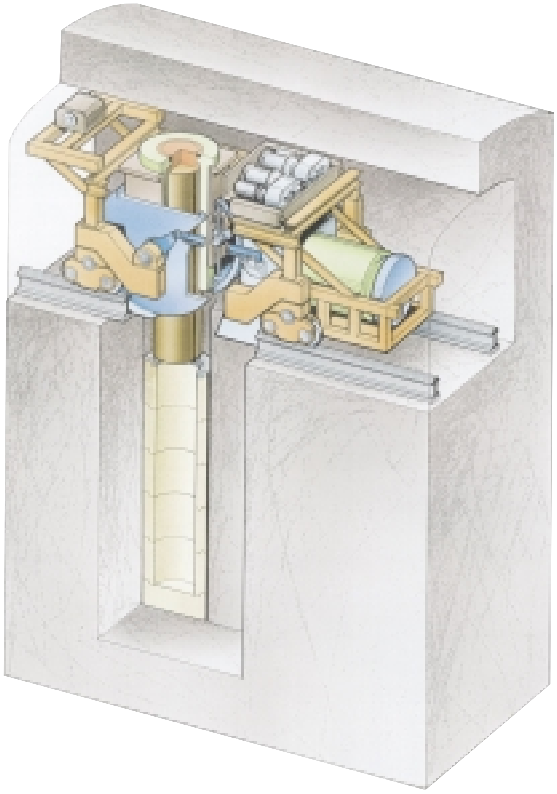


Figure 7-12. *Schematic drawing of the deposition machine that will be tested in the Äspö HRL.*

7.6.5 Testing of backfilling methods

SKB plans to test different backfill materials on a full scale at the Äspö HRL (Backfill and Plug Test). The main goals of the project are to:

- develop and test materials and compacting method for backfilling of blasted tunnels,
- test the backfill's function and interaction with surrounding rock,
- develop and test method for and performance of plugs for temporary sealing of deposition tunnels.

The test will be conducted in a tunnel at the 420-metre level. The inner part of the tunnel is backfilled with a mixture of 50 percent bentonite and 70 percent crushed rock and the outer part with crushed rock alone. A layer of pre-compacted blocks consisting of 50 percent bentonite and 50 percent crushed rock is placed nearest the roof in the outer part of the tunnel. The test tunnel is sealed with a concrete plug.

This compacted with inclined layers, which is a technique developed in earlier tests /7-39/. During the test, the sealing capacity of the backfill and the concrete plug will be measured. When the measurements are finished, the backfill will be removed for examination and analysis.

7.6.6 Testing of retrieval

Since the deep repository is designed in such a way that it is possible to retrieve deposited canisters, it is necessary to develop and test the method for retrieval as well. The main goals of the project are to, under realistic conditions:

- develop and test the method for freeing a canister from water-saturated and swollen bentonite,
- demonstrate how a freed canister can be retrieved.

The retrieval tests will be conducted at the Äspö HRL, in a new tunnel at the 420-metre level. Two full-sized canisters will be placed in deposition holes and surrounded with bentonite. The canisters will be equipped with electric heaters and the bentonite blocks with some instrumentation. The deposition holes will be sealed with concrete plugs.

The deposition holes will be left for 3–5 years to give the bentonite time to become saturated with water. During this time, equipment for freeing of canisters will be designed and manufactured. When the bentonite is saturated, the two test canisters will be freed and lifted out.

8 Safety assessments

In the safety assessment, knowledge and data are combined in an integrated evaluation of safety. The safety assessment enables us to describe the performance of the deep repository from the start and simulate its evolution forward in time.

The safety assessment is not a static tool. It is developed and refined as research advances the frontiers of knowledge concerning all the factors and processes that must be taken into consideration. Conversely, the safety assessment can reveal where knowledge gaps exist and thereby help us to prioritize our research efforts. At present, SKB is working on a new safety assessment (SR 97), which will be presented in 1999.

Renewed safety assessments will be required on several occasions in conjunction with the siting, construction and commissioning of the encapsulation plant and the deep repository. The assessments presented by SKB at these times must meet the standards of the safety and radiation protection authorities and show that the system satisfies the safety requirements.

8.1 What is a safety assessment?

The long-term safety of a deep repository is evaluated in safety assessments. What should a safety assessment do? In simple terms, its purpose is first to describe carefully what the deep repository looks like after the repository has been closed. Then it analyzes how the repository can be expected to change with time in various ways and what consequences the changes might have for safety.

The safety assessment analyzes how the repository changes with time and what this means for safety

To start with, a description of the repository's appearance or structure has to be determined. The description of the repository includes:

- dimensions and material composition of the fuel, its content of radionuclides, etc,
- dimensions and material composition of the copper canister and the cast iron insert,
- dimensions and material composition of the buffer,
- dimensions of deposition holes and tunnels in the rock, a description of the rock's fracture system and the groundwater's composition on the repository site.

The repository will undergo various kinds of changes with time. The changes are in general very slow, but on the other hand they proceed over very long periods of time.

Internal processes in the repository
- chemical
- thermal
- hydraulic
- mechanical

Some changes are chemical in nature, e.g. corrosion of the copper canister or chemical changes in the buffer. Thermal changes also occur as the energy that is liberated by the radioactive disintegrations in the fuel is transformed into heat, causing a heating of the entire repository. Other changes are hydraulic, i.e. related to flows of water and gas in the repository. An example is that the buffer absorbs water, eventually becoming water-saturated. Mechanical changes are exemplified by the fact that the water-saturated buffer swells and exerts a mechanical pressure against the canister and the walls of the deposition hole.

Criticality

Condition (for example in a nuclear reactor) where the number of neutrons released by nuclear fission is balanced by the number of neutrons being absorbed, resulting in a self-sustaining chain reaction

External processes

- climate changes
- earthquakes
- intrusion

The changes are driven or caused by a variety of processes which can also usually be characterized as thermal, hydraulic, mechanical or chemical. Heat conduction in the buffer, for example, is a thermal process, water saturation of the buffer is a hydraulic process, while copper corrosion is a chemical process. Nuclear-physical processes also enter the picture. It is, for example, important that criticality never be reached in the repository.

The processes are almost without exception dependent on each other. For example, the energy that is liberated in connection with the radioactive disintegrations in the fuel leads to heating of the fuel, which in turn (via heat conduction) causes heating of the canister, the buffer and the rock. Heating makes the rock want to expand a little, giving rise to mechanical stresses and minor movements in the rock.

All of the processes mentioned above take place inside the repository and can therefore be termed internal processes. The repository is also affected by external changes, such as climate changes and large-scale movements in the bedrock that can give rise to earthquakes. Another type of external impact could be if man in the future intentionally or inadvertently intrudes into the repository or its vicinity, see Figure 8-1.

8.2 System description

To carry out a safety assessment, it is first necessary to compile a description of all active processes in the repository, how they influence each other and how they influence the structure and function of the repository. Preparing such a system description is therefore the first task in a safety assessment. The system description for SKB's safety assessments is done roughly as follows:

1. The repository is divided into the four parts fuel, canister, buffer and geosphere, see Figure 8-1.
2. For each part, a list is made of all active processes. The processes are divided into the categories thermal, hydraulic, mechanical and chemical to lend more structure to the description.
3. For each process, a description is made of how it affects the repository and how it is linked to other processes.
4. Each process is documented according to a set template which includes a general description of the process, a presentation of the results of model studies and experimental studies, a discussion of the quality of and shortcomings in our knowledge of the process, and particulars on how the process can be handled in the safety assessment. Such documentation will be presented in the coming safety assessment SR 97.
5. For each part (fuel, canister, buffer, geosphere), all processes and their interrelationships are compiled in a diagram. The diagram for a given part of the repository shows how this part influences and is influenced by adjoining parts of the repository.

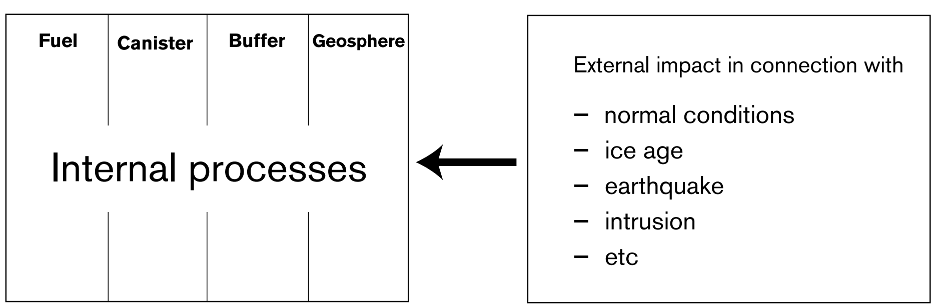


Figure 8-1. *The repository has an initial appearance or state. Its evolution is then determined by internal processes and environmental impact.*

In short, the system description tells what the repository looks like and how it changes in different situations. The description then serves as a basis for the safety assessment.

8.3 Analysis of different scenarios

Evolution assuming undisturbed conditions

Repository's isolating capacity is evaluated

How, then, is the actual safety assessment carried out? First the expected evolution of the repository with undisturbed conditions is described, in other words all barriers are assumed to be engineered in accordance with given specifications and the external influences acting on the repository are assumed to be roughly the same as today. How do such processes as the radioactivity of the fuel, heating of the rock, corrosion of the copper canisters etc. evolve under these conditions? These and other questions are answered by compiling existing knowledge concerning the involved processes and by different types of calculations. In the assessment, the system description is used to keep track of all component processes and their influence on each other.

In the description of the undisturbed evolution, the isolating capacity of the repository is particularly evaluated, i.e. particular attention is given to the question of how long the copper canisters can be expected to retain their isolating capacity under these conditions.

Evolution assuming changed conditions

Choice of scenarios is an important step

When the evolution of the repository assuming undisturbed conditions has been analyzed, the question is posed as to what happens if the premises for this evolution are disturbed in different ways. What happens, for example, if some of the copper canisters are defective from fabrication? How is the repository affected by an ice age or by other climate changes? What might the effects of an earthquake be, or of future human intrusion into the repository?

The sequence of events in each of these different situations is studied, in other words different scenarios are analyzed. Each scenario is analyzed in detail, and here again the system description is used in order to capture all aspects of the evolution. The choice of scenarios is an important step in a safety assessment and is discussed further in section 8.4. Two of the most important scenarios deal with copper canisters with fabrication defects and ice ages.

Copper canisters with fabrication defects

Repository's retarding function is analyzed in detail

In the scenario with defective copper canisters, the retarding function of the repository must be analyzed in detail. How can water enter a damaged copper canister, and how is the cast iron insert affected by the water? How long can it be expected to take before the water comes into contact with the fuel, and at what rate will the fuel then be dissolved? How can the radionuclides then escape from the canister, penetrate through the buffer and be transported to the biosphere by the groundwater? What happens in the biosphere, how do radionuclides circulate in nature, and how might they come into contact with man? All of these questions are dealt with in the scenario with initial canister damages, largely by means of calculations. The calculations result in estimates of radiation doses to humans in the vicinity of the repository. The doses are compared with the limit values for releases from a deep repository set by SSI. The limit values are strict and lie well below the natural background radiation.

Ice ages

In analyzing an ice-age scenario we are seeking answers to questions such as: When can an ice age be expected, and how long will it last? What might the extreme situation be like around the repository then? How fast does the ice cover grow, and how thick does it get? What mechanical stresses is the bedrock subjected to by the weight of the ice cover?

How does the groundwater's flow pattern change and how is the groundwater's composition affected by the changed conditions? Could the new situation affect the isolating capacity of the copper canister? Can, for example, a change in the groundwater's composition adversely affect copper corrosion? Can the mechanical stresses from the ice cover lead to rock movements that could damage the canisters? If the conclusion is that some canisters might be damaged, the retarding capacity of the repository during an ice age must also be analyzed. Furthermore, we need to investigate how initially damaged canisters are affected by an ice age.

8.4 Choice of scenarios

The choice of scenarios in a safety assessment is made with the objective that they should together provide a reasonable coverage of what can be expected to occur in the future and what the consequences would be for the repository. What can be done to ensure that this coverage is as comprehensive as possible? Some of the work can be systematized relatively easily. For example, it is possible to go through all aspects of the initial state of the repository step by step and ask what variations might reasonably be expected to occur and how these variations might conceivably influence the evolution of the repository. Climate changes and earthquakes can be studied using scientific methods where the laws of nature set the limits of what can reasonably be expected to occur.

Most difficult to predict human actions

The most difficult-to-handle scenarios are perhaps those where an attempt is made to predict how people will behave in the future. Here as well there are methods for systematic analysis, but it is nevertheless necessary to approach the subject with an open mind. Sociological and psychological studies made in many countries of independent groups have shown that there are many conceivable situations where man could affect the repository in different ways. These may involve different forms of exploitation of the bedrock such as extraction of minerals or geothermal heat, heavy pollution of the groundwater or situations in which it is decided to retrieve the spent fuel to extract more energy. In the latter situation people are aware of the repository's existence, while the former ones become more critical if knowledge of the repository has been lost. We also postulate situations where information on the repository has been partially lost and try to get an idea of what people might do then.

Lots of situations are postulated in these different ways, after which a number of representative scenarios are selected for detailed analysis.

The results of the analyses are compiled into an overall picture of the repository's safety. The assessments are scrutinized frequently by experts inside and outside the country. Examples of assessments that have been performed for the projected Swedish system for deep disposal of spent nuclear fuel are found in /8-1, 8-2, 8-3, 8-4/.

8.5 Deficiencies in the underlying information

An important part of the account in a safety assessment is demonstrating how different deficiencies and inadequacies in the database on which the assessment rests have been evaluated and managed. Such a quality review is not a separate activity, but an integral and necessary part of the entire assessment.

Quality review integrated part of safety assessment

Some deficiencies in the underlying information concern qualitative questions:

- relating to processes. Have all important processes been identified? Do we understand how the processes influence each other? Do we understand what fundamental mechanisms lie behind the processes?
- relating to external impact. Have we thought of all important types of external impact? This question is closely related to the choice of scenarios.

There are also quantitative questions:

- relating to the initial state. How well do we know the initial state of the repository, for example the fuel's content of radionuclides on deposition?
- relating to processes. How well do we understand the processes quantitatively? Even if the mechanism is well understood, necessary data for the quantitative description may be deficient. An example of this is radioactive decay. Even if the mechanisms behind radioactive decay have been thoroughly investigated, it is possible that data such as half-lives for different decay chains are deficient.
- relating to external impact. How well can we quantitatively determine different types of external impact, for example conditions during an ice age?

Have we thought of everything?

Qualitative questions of the type "Have we thought of everything?" and "Are all processes and different types of external impact included?" can only be dealt with qualitatively by showing how all information that has emerged from decades of research in Sweden and other countries is included in the assessment. SKB, like most similar organizations in other countries, has its own databases where such information is collected. The databases are one way to systematize the search for information. We get some help by studying how natural systems that resemble the disposal system have performed over long periods of time (natural analogues). This enables us to determine whether our knowledge of chemical and physical processes is adequate for understanding the changes that have occurred. The endeavour to take all available information into consideration also includes having a good system description and a carefully conceived methodology for execution of the safety assessment.

Do we understand the different processes?

The qualitative questions concerning our understanding of different processes can often be handled with pessimistic assumptions. For example, the nuclear fuel is enclosed in metallic cladding tubes, see Figure 4-1. In order for radionuclides to be able to escape from a defective copper canister, the cladding tubes must be broken. If water enters a broken copper canister, the cladding tubes will eventually be exposed to corrosion. It will probably take thousands of years before the tubes fail, since the material has been chosen to withstand the inhospitable conditions in a nuclear reactor. The corrosion processes for the material in the cladding tubes are not fully understood, however. In the safety assessment, SKB therefore often chooses not to take credit for the barrier function of the cladding tubes, but instead to assume that all tubes are broken from the start. In this way, by being deliberately pessimistic in dealing with a process, we can be sure that the safety of the repository will not be overestimated.

Worst case scenarios set the limit

Quantitative deficiencies are also often dealt with by using pessimistically chosen data. The original content of radionuclides in the fuel, for example, cannot be calculated exactly. The calculation results instead in a range of values. We then pessimistically assume that the actual value is the highest one within the specified range.

An important part of the presentation of a safety assessment is to show how deficiencies in the underlying information on which the assessment rests have been evaluated and handled. Some of these deficiencies can be remedied by further research, and the safety assessment is therefore an instrument for prioritizing of research efforts.

8.6 The safety assessment as a prioritizing instrument

Safety assessment reveals knowledge gaps

A well-executed safety assessment should, besides providing an evaluation of the long-term safety of the repository, be able to be used as a prioritizing instrument for research on the safety of the repository. The results of the assessment should be of assistance in determining which processes it is urgent to acquire more knowledge of, but should also indicate when further knowledge cannot be expected to lead to any appreciable improvement of the safety report. It is then particularly important to evaluate the reporting and handling of the different types of deficiencies associated with the information on which the safety assessment rests.

8.7 Programme for future work

The programme for the coming three-year period has three main items: production of Safety Report 97 (SR 97), evaluation of SR 97 and further development following the evaluation. A more detailed presentation of the entire programme for the safety assessment is given in /8-5/.

8.7.1 Safety Report 97, SR 97

SKB has long experience of assessing the safety of a deep repository, see section 2.5. With time the body of information for the safety assessments has grown and become more complete, at the same time as the method has matured. This has made it possible to find a more fixed structure for future safety assessments.

To find the forms for such a structure, we presented a proposed template for future assessments in Safety Report 95, SR 95. SR 95 was reviewed as a part of RD&D-Programme 95, and SKI concluded the following /8-6/: “SKI finds that SKB’s template for safety assessments (SR 95) comprises a good and flexible framework for future safety reports, but observes that parts of the presented methodology need to be further developed and concretized.” The Government has also stated the following: “A safety assessment of the long-term safety of the final repository should, in the Government’s opinion, be carried out before an application for a permit for erection of the planned encapsulation plant is submitted to the authorities, as well as before site investigations on one or two sites are commenced.”

In response to this request, SKB will present Safety Report 97, SR 97, at the beginning of the coming three-year period. The structure and methodology for SR 97 represents a further development of the template presented in SR 95. The ambition in presenting SR 97 is to describe where science and the assessment methodology stand today when it comes to evaluating the long-term safety of a deep repository.

In SR 97, conditions on three different sites in Sweden are analyzed and compared. SR 97 will contain a number of new features:

- a systematic documentation and treatment of all important processes in the safety assessment and a new form for schematic description of the entire system of processes,
- a systematic and standardized treatment of deficiencies in numerical data for all processes that directly pertain to calculations of radionuclide transport,
- Studies of the sequence of events inside a canister with a defective copper shell,
- a comparison of three mathematical models for water flow and transport of radionuclides in the bedrock for the conditions under Äspö,
- a new method for determining the effects of earthquakes.

Three different sites are compared in SR 97

Most of these areas will, when SR 97 has been reported, be evaluated and further developed during the remainder of the coming three-year period.

When it comes to long-lived LILW (low- and intermediate-level waste), a separate study is under way on the design and long-term safety of the repository. SKB plans to report the results of this study in connection with SR 97 /8-5/.

8.7.2 Evaluation of SR 97

The reporting of SR 97 will be followed by a phase of evaluation of both the safety assessment itself and the methodology and other tools that have been used to carry out the assessment. The evaluation will be conducted both internally at SKB and externally by regulatory authorities and international experts.

Evaluation in which international experts take part

The evaluation will be focused on the new features of SR 97. This includes both methods, such as the form for system description and the method for choice of scenarios, and the quality of the background knowledge for deter-mining the effects of e.g. earthquakes and ice ages.

8.7.3 Further development after SR 97

The programme for safety assessments after the evaluation of SR 97 will be shaped by the findings of the evaluation, but the following areas for further development can already be singled out.

The system description with appurtenant documentation, in the format described above, is being used for the first time in SR 97. After SR 97 has been carried out, the system description and the documentation will be more clearly linked to different databases, both SKB's and international. The idea is that the system description can be made permanent so that it can be supplemented and reused in future safety assessments. The method for choice of scenarios will also be developed and more clearly linked to the system description. The method for handling scenarios caused by future human actions will also need to be further developed.

SKB is developing methods for
- choice of scenarios
- handling of scenarios

The programme for safety assessments also includes constant maintenance and refinement of the mathematical models for:

- fuel dissolution and radionuclide dispersal in fuel and buffer,
- groundwater flows and transport of radionuclides in the bedrock,
- flux of radionuclides in the biosphere.

SKB is developing mathematical models for
- fuel dissolution
- groundwater flows
- turnover in the biosphere

In addition, the computer programs that link all these models together will be developed so that radionuclide dispersal can be followed all the way from the fuel in the canister to the biosphere. Programs for statistical processing and graphic presentation of the calculation results are also constantly being evaluated and developed.

8.8 Future safety assessments

As the design process and site investigations proceed, the repository design will become finalized in increasing detail. Increasingly refined safety assessments must be carried out in parallel with this development. In addition, safety assessments are required for a series of permit and licence applications. We can today foresee the following occasions when comprehensive assessments will be required:

- Deep repository.
  - Selection of areas where site investigations will be conducted (SR 97).
  - Application for permits for siting, detailed characterization and construction.
  - Application for licence for initial operation.
- Encapsulation plant.
  - Application for permit for siting and construction.
  - Application for licence for initial operation.
- Evaluation of experience from initial operation and application for licence for regular operation of the entire system.
- Application for permit for closure and for decommissioning.

SR 97 is not tied to any permit application

The first planned safety report, SR 97, uses data from three previously investigated sites. This report will be submitted before the site investigations are begun and is not tied to any formal permit/licence application. The assessments after SR 97 will tie in with the permit requirements laid down in Swedish law.

The body of background data for subsequent assessments will increase as site investigations, and later also expansions of the repository, are carried out. Prior to each decision, an evaluation will be made of whether the background data and the safety assessments have achieved the maturity and given the results to justify proceeding with the work.

9 Research

SKB has been conducting extensive research since the end of the 1970s. The main purpose has been to develop the methods and gather the scientific data needed to design the multi-barrier system and assess the long-term safety of the repository. This research has laid the foundation for proceeding with the initial stage of a deep repository. This does not mean that the research is over. Continued research can further improve the knowledge base.

The research programme has several goals. The most important is to provide as good a basis for the safety assessment as possible. The research should also contribute towards optimizing the repository so that its function is achieved as efficiently as possible. Moreover, the research should provide material for judging the development of alternative methods.

9.1 Reporting of the research programme

Detailed account in background report

RD&D-Programme 95 and previous programmes have contained a relatively detailed account of SKB's ongoing and planned research. Such an account is also included in RD&D-Programme 98, but in a separate background report /9-1/. Anyone wishing to ascertain the details about SKB's research should therefore consult the background report and the references given there. The account given in this chapter aims at providing an overview and a general understanding of the purpose and direction of the research.

9.2 Scope and priorities

Continued research strengthens the scientific basis for the safety assessment

SKB is conducting research and development for the deep repository. The purpose is to evaluate the state of knowledge, identify and initiate important R&D activities, and evaluate results and the need for further efforts. The work focuses on three areas:

- Technical development, e.g. canister, bentonite, repository (see Chapter 7).
- Long-term safety, i.e. data underlying the safety reports.
- Alternative methods, e.g. partitioning and transmutation.

The goal of the research on long-term safety is to understand the processes which occur in a deep repository and which affect its ability to isolate the waste. Further, the most essential processes are quantified. The results of the research serve as input for the safety reports, which analyze the long-term performance of the barriers. The final step is to assess and report the total safety of the repository.

In addition to the R&D required to meet the needs of the safety assessment, R&D is also needed for the design of the repository and for the site investigation programme. For example, materials must be developed for use in the repository, and the site investigations require development of methods and equipment. R&D is also required for odd waste forms and for studies of alternative methods (alternative studies).

Quite often, it is not until safety is being analyzed and assessed that it becomes clear what is needed in the data supplied by research. Therefore, the process-oriented safety assessment that will be reported in SR 97 gives us a tool for systematic analysis of the need for additional research for optimization of the deep repository's design. When the results of a safety assessment are available, the following questions should be answered for the processes that have been identified, e.g. copper corrosion:

Questions for determining the need for additional research on individual processes

1. How can we handle the process today (e.g. copper corrosion) in the safety assessment?
2. How do we think the process could be handled after additional research?
3. How might new knowledge improve the results of the assessment?
4. What inputs of time and resources are required to achieve the results?
5. Are the expected results worth the cost?

Following is a list of important factors to take into consideration when prioritizing research:

List of important factors in prioritizing of research

Safety:	Are the results of importance for the long-term safety of the repository? Do they contribute to an understanding of important functions such as isolation, retardation and dilution?
Resources:	Are competent people available with the time to take on the assignment? Do we have access to or can we procure suitable equipment?
Economics:	Is it economically defensible? Partitioning and transmutation experiments would, for example, cost a great deal. Is it worth the price (cost/benefit)? Would this give us alternative solutions for layout or material that make the repository better or cheaper (optimization)?
Societal aspects or information value:	Do the results have great demonstration value? Do they contribute towards building public understanding and confidence?
Competence maintenance:	Does the work give us a chance to maintain resources or train specialists who may be essential to us in the future?
Risk:	Is there a great risk of failing, and could this have serious consequences (e.g. personal injuries, heavy material damages etc.)? Does the investigation entail unnecessary stress on the environment?

SKB is also conducting research on other methods for dealing with spent fuel

Direct disposal of spent nuclear fuel is the main strategy, but SKB is also keeping track of and supporting the development of alternative methods. It is as difficult for us as for anyone else to know with certainty what will be technically possible to do in a distant future, but by considering alternatives such as partitioning and transmutation, SKB can follow progress in the field and see whether the alternatives have any future potential. It is far too easy to become enthusiastic about new technology, where the disadvantages are not as easy to see as with more mature methods. Our own investigations of alternative methods can therefore be said to be characterized by "sceptical curiosity".

Long-term competence assurance

The research projects are conducted under contract by experts in Sweden or abroad. At present, SKB's external R&D work comprises about 150 man-years per annum, with 100 people engaged on a long-term basis. In the past 10 years, some 30 doctoral theses have been produced within the framework of our contracted research. The way the work is carried out builds up a base for recruitment to SKB, creates an awareness of the questions that are important to us and broadens the competence of the institutions.

Important knowledge fields for deep disposal include:

- materials and fabrication technology for canisters,
- fuel and fuel dissolution,
- long-term durability of canister and buffer materials,
- nuclear chemistry,
- structural geology and rock mechanics,
- groundwater chemistry and microbiology,
- impact of the repository on the environment in the bedrock,
- hydrogeology and transport of solutes in the rock,
- dispersal of radionuclides in ecosystems and effects of radiation on man and the environment.

In addition, competence is needed to carry out performance and safety assessments and to maintain up-to-date information on the alternatives.

SKB's competence needs are of course dependent on the disposal strategy adopted and the timetables to be met. As far as possible, SKB makes use of the knowledge already existing in society, but sometimes we have to take it upon ourselves to ensure that the necessary competence is available. In some areas the scope of our activities is so great that a continuity of competence is automatically ensured internally. This is true, for example, of knowledge concerning canister materials and of technology for fabrication and inspection of canisters. The technology for sealing and inspection of canisters will be further developed in the Canister Laboratory. Knowledge of rock mechanics, rock characterization and rock construction will be further refined at the Äspö HRL and during the construction phase on the repository site. The activities at these locations are expected to have such breadth and scope that it should normally be possible to meet the competence requirement by internal further training. Other areas in which SKB itself assures the necessary future competence include planning of the activities, environmental and safety assessments and project management. R&D-related activities in connection with the planning and design of management and disposal facilities are another example of this. One way to broaden the scope of these competence assurance activities is to establish active cooperation with relevant bodies in Sweden and internationally.

Another group of fields important to SKB's activities includes chemistry, geochemistry, geology and basic knowledge within systems ecology and radiophysics. The traditional education offered at universities and institutes of technology within these fields is well suited to our needs. The research we contract out often requires the engaged specialists to deepen their knowledge within fields specific for SKB, such as odd nuclides, long-term assessments or the bedrock at great depth. In order to build up competence within these fields in the long term, we also encourage the use of our research in postgraduate education.

Essential to have laboratory resources for experiments with radionuclides

A third group consists of competencies that are narrow but important to SKB, often of a key character. Examples are nuclear-chemical competence for characterization of spent fuel and other radioactive waste, as well as for studies of transmutation. Other examples are knowledge of the chemistry and microbiology of deep groundwaters for studies of chemical reactions and material transport in the bedrock. Swedish competence is also narrow as regards the long-term stability of the protective clay barrier and future condi-tions which can affect long-term repository performance. SKB intends to give long-term support to these areas and assure adequate competence in the future. This also includes retaining physical resources that are unique in some respects, for example radiation-shielded cells, the opportunity to work with alpha-emitting radionuclides, specific measuring instruments, etc. SKB will work for broad European and international cooperation in this field as well. It is possible to establish competence centres in Europe and internationally that are too specialized to maintain at the national level.

In summary, our task is to ensure the continued existence of the necessary competence both inside and outside SKB by means of the following measures:

- Awarding research contracts to universities and institutes of technology. In this way, researchers are trained in fields that are essential to SKB.
- Awarding contracts to research institutes with access to unique equipment. In this way, equipment is maintained that is necessary to SKB (e.g. radiation-shielded cells for high-level material).
- International cooperation.

Broad international cooperation

In some cases, SKB may directly subsidize an educational programme for the sole purpose of preserving a unique competency. This is only in exceptional cases, however. As a rule, our primary interest is in the results of the research we contract out, and competence maintenance is a secondary benefit included in the bargain.

9.3 Overview of research areas and research programmes for the deep repository

The safety assessment is based on the knowledge possessed by SKB on the waste, the radionuclides, the barriers and the biosphere. If this knowledge needs to be improved, we conduct our own investigations or avail ourselves of the results of investigations conducted elsewhere in the world. Current state of knowledge and plans are reported and reviewed. A thorough description of ongoing and planned research and development is provided separately in a special background report: “Detailed programme for research and development 1999–2004”. The background report presents background, state of knowledge, goals and programme in all the different research areas where SKB is conducting investigations. The report also includes an account of all the R&D projects being pursued by SKB, for example at the Äspö HRL and within the EU. In the review of RD&D-Programme 95, the requirement was expressed that SKB should demonstrate how the supportive R&D work ties in with the safety assessment. For this purpose a table has been compiled in the background report showing how the R&D activities are linked to the important safety-related processes.

Spent fuel

The durability of the spent fuel in the groundwater was first studied by SKB in 1977 (KBS project). The current programme was established in 1982. Our knowledge of corrosion and dissolution of spent fuel comes mainly from the many experiments with fuel in water where pieces of fuel are suspended in glass flasks with groundwater and samples of the water are taken regularly. These experiments are mainly conducted in radiation-shielded cells at the Studsvik fuel laboratory. It has been a very comprehensive programme, and great efforts have been devoted to analyzing the leachate solutions. Recently, we have also begun measuring redox potential and pH in the leachate solutions. The solubility of uranium dioxide, which the fuel for the most part consists of, is dependent on these two particular parameters. Such measurements are difficult to make in these experiments, but important if fuel corrosion is to be followed in detail.

Redox potential
Measure of groundwater's capacity to reduce or oxidize different substances. Water that contains oxygen is oxidizing and has positive redox potential. Deep groundwaters are reducing with a negative redox potential.

Experiments with fuel in water-saturated bentonite clay were started back in 1985. The purpose was to study both fuel corrosion and diffusion of radionuclides in the buffer. It was also important to test how the chemical environment created by the buffer affects the fuel. A total of ten bentonite-fuel experiments were started, the longest went on for more than six years, and comprehensive analyses were performed. The results are now available and show, for example, that the actinides plutonium and neptunium diffuse much more slowly than expected, uranium slightly faster and americium just as expected. If the relative quantities of different radionuclides that have been released from the fuel and ended up in the clay are compared with the corresponding quantities in the fuel, the proportions are found to be unchanged. This is typical of a process known as congruent dissolution and indicates that the actinides are bound in the uranium dioxide that comprises the fuel matrix. Accordingly, the actinides cannot be leached out until the fuel matrix dissolves, releasing them.

pH
Measure of acidity. The lower the pH, the more acidic the water. Water with ph=7 is neutral (drinking water)

Fuel matrix
The ceramic material that comprises the nuclear fuel

It is especially important to know the chemical properties of the actinides in the spent fuel, e.g. uranium, plutonium, neptunium and americium. The calculations show that they are poorly soluble in the repository. The experiments also show this, but fundamental chemical data for several of the actinides are deficient, making it difficult to carry out accurate solubility calculations. An important actinide such as plutonium has very poor solubility in the chemical environment in the repository, but measuring the constants that control solubility is very difficult. Among other things, it is difficult to analyze the low concentrations that are involved. The goal of our work in this area is to improve the chemical database.

Radiolysis
Decomposition of water caused by radiation from the waste

Radiolysis is an important chemical process. Experiments and calculations show that the following chain of chemical reactions can take place when fuel comes into contact with water:

1. Production of oxidants by radiolysis (e.g. hydrogen peroxide and oxygen).
2. Further oxidation of the uranium oxide, which is the predominant component of the fuel (fuel matrix).
3. Dissolution of the further oxidized areas on the surface of the fuel.
4. Formation of new solid uranium phases (secondary uranium phases).

Influence of hydrogen is important

It is probable that hydrogen plays an important role in this context. Hydrogen is liberated by radiolysis, and is also formed when iron corrodes. So far, SKB has assumed that hydrogen does not participate in any further reactions, but leaves the fuel and disappears out into the groundwater. But if the hydrogen should react, the oxidants will be consumed, the above chain of chemical reactions broken and the fuel matrix protected. The investigations are continuing, and SKB's goal is to develop a good and realistic model of fuel dissolution by 2001. The models used to date have exaggerated the effects of the reactions so as not to underestimate the consequence of the fuel's coming into contact with water.

New model of fuel dissolution by 2001

Canister for spent fuel

The canister's capacity to isolate the waste is important for long-term safety. The requirements that must be fulfilled by the canister are described in Chapter 7. The design of the canister and the programme for continued work are also described there.

Research on the canister is described in Chapter 7

Ongoing development of knowledge and further testing of models for the corrosion of materials in the canister will continue, for example by means of the experiments in the Äspö HRL. Another important area for the safety assessment is stress corrosion accompanied by cracking. The experimental investigations at the Department of Material Science and Engineering (KTH) continue.

Buffer and backfill

Buffer

Material between canister and rock

Bentonite

Clay of volcanic origin with suitable swelling properties

Smectite

Clay mineral that absorbs water and makes the clay swell

Bentonite is a natural clay that contains the clay mineral smectite. Smectite possesses the property of being able to absorb water and swell, which gives the bentonite a sealing capability. Bentonite was first suggested as a buffer between canister and rock in the 1970s. Bentonite from Wyoming in the USA with the trade name MX-80 Volclay has a high content of swelling smectite. Thanks to its good properties and high quality, MX-80 has been used by SKB as a reference material from the very start. A bentonite with slightly lower quality may also serve the purpose, and such bentonite exists, for example in Denmark and northern Germany.

There are a number of requirements which the buffer material must satisfy (see section 7.1.2). The reference material MX-80 satisfies these requirements, and we will also examine the bentonites from Denmark and northern Germany to see if they are satisfactory. Bentonite may also be included in the material used to backfill the deposition tunnels. However, the requirements are slightly different for the tunnel backfill compared with the buffer in the deposition hole (see section 7.1.4). The lower density of bentonite in backfill makes is slightly more sensitive to the salt content of the groundwater. This will be tested in full-scale experiments in the Äspö HRL.

The bentonite buffer must permit gas to be transported through it

The safety assessment needs models that describe the properties of the buffer in various respects. One question that is explored in depth is the transport of gas through the buffer. If a canister is damaged so that the cast iron inside the copper shell corrodes, hydrogen is formed. If this occurs, the gas must be able to escape when the pressure gets high, without damaging the buffer. Experiments with gas and bentonite are currently being conducted, and a calculation model will be devised that describes the process. This is being done in cooperation with organizations in Finland, France, Japan and Switzerland that are also interested in using a bentonite buffer.

Calculation models have been developed which describe how the buffer absorbs water and swells, and what influence the heat has on this. To test the models, SKB has carried out calculations using measurement values from Japanese experiments. The tests were conducted underground in the Kamaishi Mine in Japan. The FEBEX experiment that is being conducted in Grimsel, Switzerland, and the Prototype Repository Experiment that will be conducted in the Äspö HRL will provide further data for testing the reliability of these calculation models.

Influence of cement on bentonite is studied

We would like to use cement in a deep repository for spent fuel in order to reinforce the rock by grouting. Other areas of application are also possible. This must naturally not jeopardize the long-term performance of the bentonite. For this reason, tests have been conducted with cement in combination with bentonite and hot water. The tests have been in progress for up to 16 months. Some small changes can be seen in the bentonite, which are being further investigated. The results will provide guidance in the use of cement near the buffer in the deep repository.

The long-term chemical stability of the bentonite and questions regarding how the buffer should be applied in the deposition hole are examples of areas that will be further investigated.

Structural geology and mechanical stability of the rock

The host rock is an important barrier that is supposed to protect the canister. There are a number of requirements which the rock must fulfil (see section 7.1.3). Prior to making a decision on the site of the deep repository, we are improving our knowledge of margins in the rock's capacity to isolate the waste and protect the repository.

An important question for structural geology is the positioning of the repository with respect to major fracture zones. Prior to the site investigations, we will report how we intend to examine the susceptibility of the site to rock movements, how the stability of the fractures will be assessed, and how the repository will be positioned in relation to this.

Another important task is to compile a report by 2001 which describes how SKB will investigate and describe the rock-mechanical conditions on the site. The report should also show what effects the rock excavation work will have in this context, what effects the heating of the rock by the waste will have, and how the detailed layout of the repository will be adapted to this knowledge.

Earthquakes can lead to displacements along fractures in the rock. A review has therefore been made of all available data that relates magnitudes of earthquakes to length, aperture and displacement in fractures or fracture zones. It is an important investigation, since it provides an opportunity to analyze the effect of an earthquake on the repository. Studies of earthquakes and their possible impact are preferably conducted on the international level – major earthquakes are, after all, rather rare in Sweden. SKB is therefore cooperating with Japanese PNC in an investigation of the impact of earthquakes. This investigation is being conducted in the research mine in Kamaishi. We are also making use of the results of the Europrobe/Eurobridge project that is studying the Baltic Shield.

Magnitude

A measure of how much energy is released by an earthquake

PNC

Power Reactor and Nuclear Fuel Development Corporation - Japanese state research organization for nuclear energy

A phenomenon that has not yet been satisfactorily explained is accumulations of boulders at certain locations, known as crystalline rock caves. SKB is participating in the exploration of one such formation, the Boda Caves at Iggesund, see Figure 9-1.

Methods such as seismic reflection have been further refined so that we can identify such geologic structures as horizontal or flatly dipping fracture zones down in the rock. These structures may otherwise be difficult to find in surface surveys, at least if drilling has not been done. Vertical structures are simpler since they are manifested at the surface.

Figure 9-1. *The Boda caves.*

Mechanical stresses in the rock can be measured in different ways, e.g. overcoring and hydraulic fracturing. The measurements are performed in bore-holes. SKB is examining how representative such measurements are for the whole rock and what influence depth has. In Laxemar, rock stresses have been measured down to 1400 metres (see also under the heading "Deep drilling at Laxemar" below). Rock stresses can influence the stability of the tunnels. This may be of importance for the deep repository, and we are therefore participating in the development work in this area.

Water flow and transport

Transport of solutes in the rock is dependent on groundwater flow and flow paths, among other factors. Measuring the hydraulic properties in the area where the repository will be located and describing this with flow models is important for the safety assessment. Models and measurement methods for this purpose are progressively being improved.

It is not simple to go from e.g. measurements of the rock's capacity to conduct water, which are performed in boreholes, to calculations of the water flow on a scale that encompasses the entire area in which the repository will be situated – even if several boreholes are utilized and each borehole is divided into a series of measurement sections. How this is best done is explored by means of measurements and calculations. On a very small scale, investigations have been made in a laboratory of how water runs in an individual fracture. On a large scale, we have studied how groundwater movements over entire regions of the country influence the flow in the repository. The conclusion from the latter investigation is that it is the local conditions that control the water flow. We would therefore like to examine more closely the importance of the local conditions near the ground surface, i.e. lakes, watercourses and the shape of the land surface (topography) in the area. The movements of the water near the ground surface, such as groundwater discharge, are also of special interest for the biosphere studies (see under the heading "Radionuclides in the biosphere" below).

TRUE

Tracer Retention Understanding Experiments.

International research project at the Äspö HRL for studying how radionuclides move in rock fractures

Since it is so important to be able to go from small-scale measurements in a borehole to large-scale calculations, SKB has conducted numerous tests in the field at Äspö, for example TRUE (Tracer Retention Understanding Experiments). Different calculation models have been used and compared with each other. More such exercises are planned.

By 2001 we are supposed to have developed a programme that shows which measurement methods and which calculation models we can use on an investigation site. Most of the work in this area is being carried out at the Äspö HRL.

Groundwater chemistry

The canister and the bentonite must be stable in the chemical environment that prevails down in the repository. That is why it will be important to sample and analyze the deep groundwater in conjunction with the site investigations. SKB will measure the chemical environment as it is today and furthermore determine how stable it is. The construction of the repository will affect the originally undisturbed environment, but after closure it is assumed that the original chemical environment will essentially be restored. Furthermore, we must assume changes will occur in the future, for example another climate, which could affect the groundwater chemically. Äspö is well-suited for such studies, and much of the hydrochemical research being conducted by SKB is tied to Äspö and the international projects being conducted there.

Groundwaters at a depth of several hundred metres were not very well known when SKB started its activities in the late 1970s. This is even more true of groundwaters at greater depths, 1,000 metres and below. This knowledge has increased considerably, however, and SKB has contributed towards this development. Sampling and analysis of groundwaters from study sites in different parts of Sweden, the Stripa Project and Äspö have contributed to this. A good example is the mobile chemistry lab, which can be used to take water samples from a borehole and perform analyses directly on the site.

The methods of evaluating the analysis results have also been developed, for example calculations using the computer program M3. A mathematical method called "principal component analysis" is used for this. It is a way to find relationships between a large number of measurement values. M3 can be used to process large quantities of analysis data and find traces of contaminants and chemical reactions in the groundwater. Calculations with M3 are a more objective way to work than going through data manually and trying to find relationships, which was the customary practice before. M3 has been tested thoroughly at Äspö and has also been used in analogue studies (the Oklo and Palmottu projects).

A current area of research and demonstration is the stability of the chemical environment at repository depth. Construction and operation will entail disruption of the water flow and water chemistry. The impact of this is being investigated in projects being pursued at Äspö, such as the REX Project (Redox Experiment on detailed scale) (see also the section below on the Äspö HRL).

REX

Redox Experiment on detailed scale

International research project at the Äspö HRL for studying how oxygen introduced by rock excavation works influences geochemical conditions

The composition of the water in different parts of the rock can provide important clues for describing how the water moves. Sampling therefore needs to be done both in the fractured parts of the rock where the water moves easily and in the less transmissive parts where the water is more stagnant. Moreover, the deposition holes will be located in the more intact parts, so it is extra urgent to take water samples in nearly impervious rock, as difficult as that may be. Special equipment has been developed for this purpose and is now being used in the Äspö HRL.

In preparation for the site investigations, the most important hydrogeochemical parameters are being compiled with an explanation of why they are so important and a description of how they will be measured. Groundwater chemistry is so important that unfavourable conditions can influence the choice of site and to some extent even the layout of the repository.

Radionuclide chemistry

The chemical properties of the radionuclides determine how mobile they are in the buffer and rock. The assessment of long-term safety begins with an inventory of the radionuclides contained in the waste and their chemical form in the waste. Iodine I-129, for example, is an iodine isotope with a very long half-life. It is both highly soluble and highly mobile. Another important radionuclide is caesium-137. It is present in spent fuel, is highly soluble like iodine but tends to adhere to clay minerals. Caesium-137 is therefore placed in an intermediate group when it comes to mobility in buffer and rock. A radionuclide with very low solubility and mobility is plutonium. Plutonium is present in the fuel as a poorly soluble oxide, and dissolved plutonium is sorbed strongly by clay and other minerals in buffer and rock. Since sorption as well as diffusion are very important processes for the two barriers buffer and rock, SKB will continue fundamental studies of these phenomena. More applied measurements will be needed in conjunction with the site investigations. A new method is therefore being developed for measuring diffusion of radionuclides in the microfractures in the rock, known as matrix diffusion. Matrix diffusion is important, since it contributes to reduced mobility of dissolved radionuclides.

The substances that are bound most strongly to the fracture surface and in the rock matrix also have a strong tendency to form complexes with other substances or to adhere to colloids in the water. This could at worst increase both the solubility and the mobility of some of the radionuclides present in the waste.

Isotopes

Atoms with different atomic weights but the same chemical properties - i.e. the same element. Elements usually occur as several isotopes, some of which may be radioactive and others stable

Radionuclide

Radioactive isotope

Half-life

The time required for the quantity of a radionuclide to be reduced to half by radioactive decay

Sorption

Uptake of solutes on e.g. fracture surfaces

Matrix diffusion

Diffusion of solutes in the water-filled pores between the mineral grains in the rock matrix

Colloids

Particles that are so small they don't sink to the bottom of liquids

Complexes

In this context, dissolved compounds of radionuclides and organic molecules (humic substances)

Microbes

Tiny organisms, e.g. bacteria and virus

SKB has studied colloids and complexes since the late 1970s and arrived at the conclusion that if the repository is situated in a host rock with pure, deep groundwaters, this is not a problem. The concentrations of both complexing agents and colloids are too low to be of any importance.

It is also important to study the repository itself and the disturbance caused by the new materials in the host environment. The fuel could possibly give rise to colloidal particles in the groundwater. Filtering colloids is therefore an important function of the buffer, and one which we check extra carefully. Other substances in the repository that could affect radionuclide chemistry are concrete and steel. Concrete raises the water's pH value and iron corrosion evolves hydrogen. Investigations will show how much of these substances can be allowed to remain in the repository on closure.

Microbes in the deep repository are of special interest since they can alter the environment in which they live. The most important aspect, however, is not the impact of microbes on the radionuclides, but on corrosion of the canister. That is why the study of microbes is being prioritized and is of interest for both the chemistry programme and the canister programme.

Radionuclides in the biosphere

The biosphere is the part of the earth in which life exists, for example on the surface of the earth, in lakes, in the air and down in the ground. If radionuclides from a repository reach the ground surface, they can migrate in the biosphere and ultimately reach man. Calculations are performed in the safety assessment and the consequences of a release are analyzed. The calculations are complicated by the fact that the biosphere exhibits great local variations, and it must also be assumed that great changes can occur with time. Nothing drastic such as a new ice age is required for this. Postglacial land uplift in a near-coast region that is slowly but surely making land of sea – perhaps within the course of a few thousand years – is enough. It is possible to make realistic calculations for the next 1,000 years if current conditions on the chosen site are well understood. But for long periods of time it is necessary to make simplified calculations based on general assumptions of what the biosphere will look like and what changes may occur. In order to reduce the uncertainties associated with a long timescale, we will concentrate on describing the most important processes, i.e. the processes in the biosphere than can give rise to radiation doses to man and expose animal and plant species.

In preparation for the safety assessment SR 97, calculations are being carried out of how radionuclides that migrate up with the groundwater are spread in the biosphere. The point of departure is the analysis of a scenario where a canister has been damaged and leaks radionuclides, which are spread with the groundwater. Via the groundwater, dissolved radionuclides can reach wells, lakes, rivers, streams, coastal districts, wetlands and agricultural areas.

Three different areas are considered in SR 97: one at the coast, one near the coast and one inland area. Experience from this provides good guidance for the evaluation of future site investigations.

What is missing is a model for how radionuclides spread in the forest with its animals and plants. The forest is the most common recipient on most sites which have been considered thus far (and for which SKB has done calculations). A new model for dispersion and accumulation of radionuclides in forest land is therefore high on the list of priorities.

Sediments can prevent radionuclides from reaching the ground surface. But at worst the sediments can thereby become a future source of contamination, for example if erosion mobilizes and disperses the sediments so that radionuclides which were previously immobilized there escape once again. Such erosion can occur, for example, when sediments on the seabed reach the shoreline in connection with land uplift. SKB is therefore studying the stability of sediments and their capacity to accumulate radionuclides. Spreading of radionuclides with particles in the water (sea, lake, watercourse) will also be further studied.

International cooperation is contributing considerably towards increasing knowledge in this area. A good example is the international project BIOMOVS II which was concluded in 1996. The new project, BIOMASS, which is being run by the IAEA has taken over where BIOMOVS II left off. A smaller study in BIOMOVS II evaluated experiments with transport of radionuclides in the soil layer. An important lesson learned from the study was that animals and plants are quite important for dispersing radionuclides. Roots and animals can contribute towards the upward migration of radionuclides from the groundwater, up through the soil layers to the ground surface. These processes will be included in the forest model.

BIOMOVS

Biosphere Model Validation Study

International project for studies of computer models that describe how radioactive substances behave in the biosphere

By 2001, SKB will have given an account of how the biosphere will be described on a future site and what importance it has. It is possible that, as an extra safety precaution, the positioning of the repository within an area may have to be adjusted to, for example, the way in which the groundwater reaches the biosphere.

BIOMASS

Biosphere Modelling and Assessment

A continuation of the BIOMOVS project

Deep disposal of long-lived low- and intermediate-level waste (LILW)

Some of Studsvik's LILW and some internal components from the power reactors contain too much long-lived radionuclides to be disposed of in SFR. Such waste can instead be disposed of in the deep repository, well separated from the canisters with spent fuel (approximately 1 km). Another possibility is that a repository for long-lived LILW is sited completely separate from the deep repository. Ordinary operational waste from CLAB and the encapsulation plant will also be disposed of in the repository for long-lived LILW after SFR has been closed. This has previously been explained in SKB's Plan Reports.

A deep repository for long-lived low- and intermediate-level waste can be situated adjacent to the deep repository for spent nuclear fuel or at another site

Nowadays, deep disposal of long-lived LILW is dealt with in the SKB project "Other Waste" (Other long-lived waste than spent nuclear fuel). As a preparation for a safety assessment, the project is working on the following:

- Inventory the long-lived LILW at Studsvik and the NPPs, and calculate the future quantities.
- Calculate the quantity of future operational waste from CLAB and the encapsulation plant.
- Calculate the quantity of other future LLW (e.g. decommissioning waste from CLAB and the encapsulation plant).
- Measure and describe the chemistry of the radionuclides in concrete.
- Describe the change of the concrete with time.
- Devise models for calculating whether radionuclides from the repository are released and migrate in the rock (i.e. adapt the safety assessment's models, which were developed for spent fuel).
- Develop the repository's design.
- Participate in international cooperation.

The last point is not least important, since considerable experience exists and a great deal of research is done within this field in countries such as the UK, Switzerland and France. We save both effort and resources by exchanging information with each other.

A great deal of research work has been devoted to investigating the chemical effects of concrete on the waste. The pore water in water-saturated concrete has a chemistry that is different from that of the groundwater in the rock fractures.

Above all, the pH is very high in the concrete's pore water. This protects the reinforcing bar from rusting, which is an advantage. But at the same time cellulose can be degraded to form products which increase the solubility of some of the radionuclides. Plutonium, for example, is strongly affected, which was how the phenomenon was discovered. Cellulose is present in some of the waste in the form of paper, fabric and wood. A great deal of work has therefore been devoted to measuring the degradation of cellulose and the effect which the degradation products have on sorption and diffusion of radionuclides in concrete. SKB will continue these studies.

The project Other Waste began with a feasibility study to test the performance of the barriers in the first design of the repository. Based on the results, a new simplified design has been proposed, and we will now analyze the long-term safety of the repository. The feasibility study included an initial inventory of both the existing and the projected future waste. That inventory is now being updated. The safety assessment is based on the new design, the most recent estimate of the waste quantity, a compilation of chemical data and calculation models which are, as far as possible, common with the safety assessments for spent fuel. The results will, according to the plans, be reported in conjunction with SR 97.

Final disposal of low- and intermediate-level operational waste

The final repository for radioactive operational waste, SFR, which is located in Forsmark, has been in operation since 1988. Since it is a fully operational facility, no research is needed there, but rock stresses, groundwater pressure and groundwater composition in and around the repository are measured continuously. Conditions in the bentonite buffer surrounding the silo are also monitored continuously.

SKB's operating licence for the plant contains a requirement that the safety assessment should be updated at regular intervals to incorporate new knowledge about the waste, the facility and the processes that are of importance for long-term safety. The results of the continuous measurements in and around the facility are also used to improve the safety assessment. To the extent that new and improved calculation models have been developed, they are also used for the evaluation. The next assessment will be published in 2000. The assessment is being carried out within the SKB project SAFE (Safety Assessment of Final Repository for Radioactive Operational Waste). The work within the project mainly involves:

- Calculation of waste quantities, radionuclides, chemicals and other material based on existing operational experience.
- Analysis of hydrological, chemical, mechanical, thermal and radiological processes in the engineered and natural barriers for the purpose of improving the model calculations.
- Refined interpretation of geologic structures and calculations of the groundwater flow in the rock.
- Inventory of the biosphere, an improved description and improved calculations.
- Updating of the scenario analysis previously performed.

Scenarios

Describe a hypothetical course of events that might possibly occur, see Chapter 8

The new calculation programs that are being used within the safety assessment have a greater capacity than before. This makes it possible to refine the calculations that are supposed to show whether radionuclides and possible toxic substances can be released and escape from the repository.

SKB is also participating in the development of measurement methods with lower detection limits for difficult-to-measure but important radionuclides, such as nickel-59. With a lower detection limit for nickel-59 we can more easily determine how components that have been situated close to the reactor core are to be dealt with. If these components contain a great deal of nickel-59, they are assigned to the category long-lived waste (see preceding section).

Äspö HRL

Building an underground laboratory on the island of Äspö (see Figure 9-2) was first proposed in SKB's RD&D-Programme 86. After the pre-investigations had been completed, the facility began to be built in 1990 and was finished in 1995. The Äspö HRL is supposed to serve as a dress rehearsal for the deep repository. Important tasks are e.g. to try out methods for site investigations, to develop technology for the deep repository, to train personnel, to furnish data for the safety assessment and to inform outsiders on technology being developed for the deep repository. The Äspö HRL entails a continuation of the tradition of international cooperation that was begun back in 1977 in the now-abandoned Stripa Mine. Today organizations from ten different countries are participating in the research in the Äspö HRL: Finland, France, Canada, Switzerland, Germany, Spain, the UK, Japan, the USA and Sweden.

The underground portion of the Äspö HRL takes the form of a tunnel from the Simpevarp Peninsula to the southern part of the island of Äspö. On Äspö the main tunnel continues in two spiral turns down to a depth of 450 metres. Smaller niches and tunnels branch off from the main tunnel to stations where the various experiments and tests are conducted, see Figure 9-3.

The time before and during the construction of the underground facility was used to test different methods and conduct site investigations. The methods, as well as the models used to describe the properties of the rock, were improved and refined. We particularly wanted to make sure that investigations in boreholes drilled from the surface provided sufficient information on the rock down to repository depth. Once underground, we could study the rock in detail from the laboratory's tunnels and shafts. This work was concentrated to the Äspö tunnel.

Äspö Hard Rock Laboratory
Investigations 1985-1990 and construction 1990-1995
Tunnel 3.5 km
Depth 460 m
Cost MSEK 500

Participating organizations from:

Finland, France, Canada, Switzerland, Germany, Spain, the UK, Japan, the USA and Sweden

Figure 9-2. *A large part of SKB's applied research and technology development is conducted at the Äspö HRL.*

Research and development at the Äspö HRL

ZEDEX

Zone of Excavation Disturbance Experiment

International research project at the Äspö HRL to study and compare changes (e.g. fracture formation) in the rock walls in connection with blasting and boring of rock tunnels

The ZEDEX Project was carried out to study how the rock was changed adjacent to tunnels and other open chambers by excavation employing different methods (blasting and boring). Some fractures are always made in the tunnel walls during excavation of tunnels in rock, and it is important to know what the "excavation-disturbed zone" looks like and how far it extends into the rock wall. The results indicate that tunnel boring causes very little disturbance of the rock. Models have been developed under the auspices of the Äspö HRL that describe the flow of groundwater of varying salinity. The international participation has been of great value in this context.

The REX Project measures how oxygen is consumed in the rock (see also the section under the heading "Groundwater chemistry" above). An experiment has been started down in the Äspö tunnel and is expected to be finished during 1999. The experiments underground have been preceded by extensive laboratory experiments.

Degassing

Gas that is dissolved in water can be emitted as bubbles if, for example, the pressure falls

Degassing of the groundwater in the rock near tunnels and boreholes is a phenomenon that can disturb measurements of e.g. water flow. This has been investigated thoroughly on Äspö. The reason for the interest is as follows: If enough gas is evolved, either naturally or by e.g. corrosion, the water flow is affected. It is also important to understand how the gas is transported from the repository. New experiments with gas and two-phase flow, i.e. simultaneous flow of water and gas, will be conducted on Äspö.

HMS

Hydro Monitoring System

The results of measurements in the rock and the groundwater were systematically collected during the pre-investigations on Äspö. This continued during the construction of the underground laboratory. Even after construction, measurement data continued to be gathered and is still being gathered. Among other things, the groundwater pressure in boreholes is monitored from the ground surface both on Äspö itself and in adjacent areas. A large number of boreholes from the underground portion of the facility are also monitored by this system, which is called HMS (Hydro Monitoring System). Monitoring of water pressure is required by a Water Court ruling.

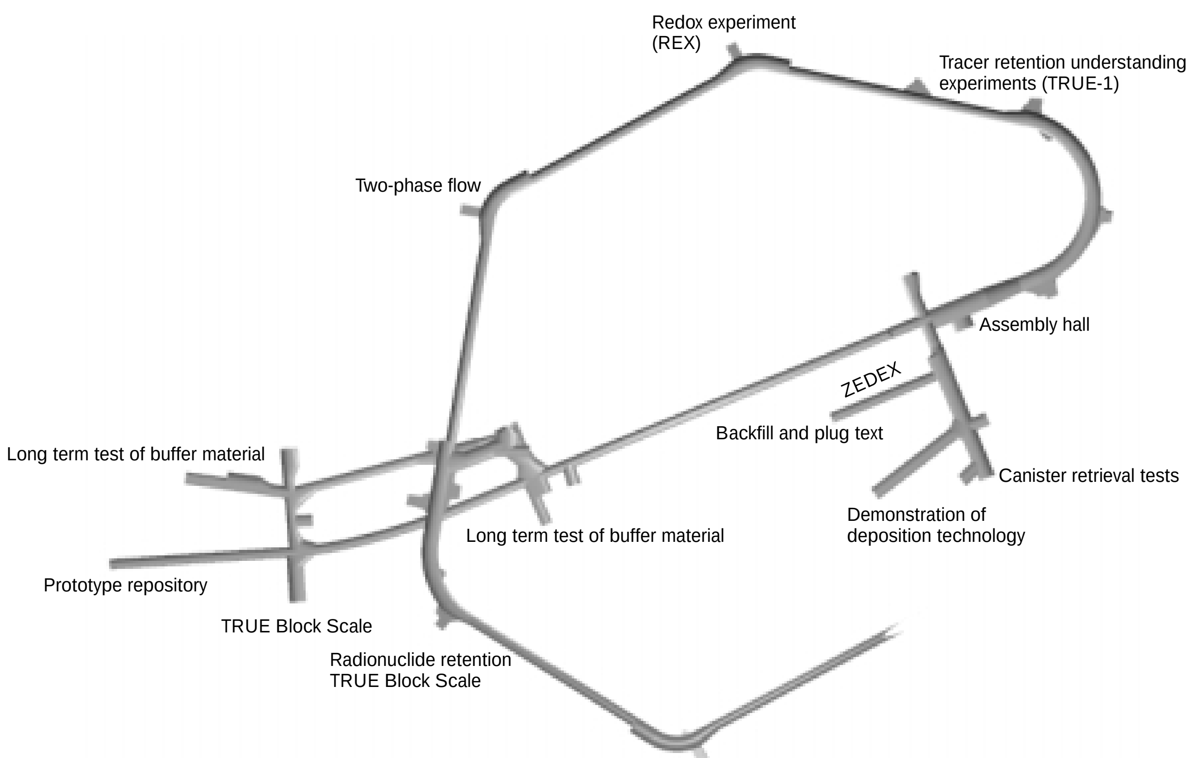


Figure 9-3. *Plan of Äspö tunnel.*

Groundwater chemistry is also monitored by regular sampling. All measurement results – water pressure, water chemistry, fracture mapping etc. – are added to SKB's database SICADA. The program RVS (Rock Visualization System) is being developed to process and visualize data from SICADA. The intention is that this system for management of measurement data will be able to be used in future site investigations.

A number of different measurement methods are being developed on Äspö for use in detailed characterization underground, e.g. radar, seismic measurements, rock stress measurements, laser scanning of tunnel walls, water sampling during drilling, etc.

TRUE is a series of experiments being performed in fractures underground in the Äspö HRL. The purpose of the experiments is to see how radionuclides migrate with groundwater in the rock and test the models that will be used in the safety assessment. Radionuclides as well as other tracers are injected via boreholes. The fractures have been carefully selected and investigated beforehand. Laboratory tests and theoretical calculations show that the rock has a considerable capacity to restrict such migration and thereby act as a barrier. This is being tested on both a large and a small scale on Äspö.

Experiments with radionuclides in the rock must be conducted with adequate safety. This limits the choice of substances and quantities that can be used as tracers. These problems can be solved by partially enclosing the experiment in a probe. The fact that the scale of the experiment is thereby small – it has to fit into the probe – is seldom a problem, since most radionuclides have very low mobility. Such a borehole probe, CHEMLAB, has been engineered. Groundwater is taken into the probe and experiments involving e.g. diffusion and sorption of radionuclides are conducted inside the probe. Tests with pieces of fuel can also be conducted in CHEMLAB and such tests are planned.

SICADA

SKB's database with geoscientific data from Äspö. It also contains data from other investigated sites

RVS

Rock Visualization System

Demonstration of important parts of the disposal system

An increasingly important task for the Äspö HRL is to test and demonstrate parts of the repository system on a full scale. This has been described in Chapter 7. Some of the different activities included are also discussed there, for example development of technology for grouting of rock, testing of deposition machine, testing of technology for backfilling, testing of retrieval (see sections 7.4 and 7.6). Most of this work is being carried out within the framework of different projects at the Äspö HRL. One important such project is the construction of the prototype repository, see Figure 9-4. It will be built in the inner portion of the bored tunnel at a depth of 450 metres. Preliminary plans call for six full-scale deposition holes spaced at intervals of six metres. Heat will be generated in the canister electrically instead of by spent nuclear fuel. Design, materials and rock will be as similar as possible to a real repository. Long-term safety cannot be tested in this manner – it would require very long times – but it is possible, by installing measuring instruments, to register how the buffer and the backfill are saturated with water, how the rock is heated, how mechanical stresses affect the rock, and how the chemistry is altered during a transition phase.

In another project on Äspö, different materials and methods for backfilling tunnels in a deep repository are being tested (Backfill and Plug Test). Introductory tests with different materials were conducted in 1995 and 1996 (different mixtures of crushed rock and bentonite). A way was then found to compact the backfill that worked better than the previous method, especially in wet tunnels. Long-term tests are planned, including experiments with a mixture of 30 percent bentonite in crushed rock, see Figure 9-5.

Handling operations such as deposition and retrieval will be demonstrated on a full scale. The demonstration project will be a complement to the prototype repository and the Backfill and Plug Test. An alternative to depositing canisters

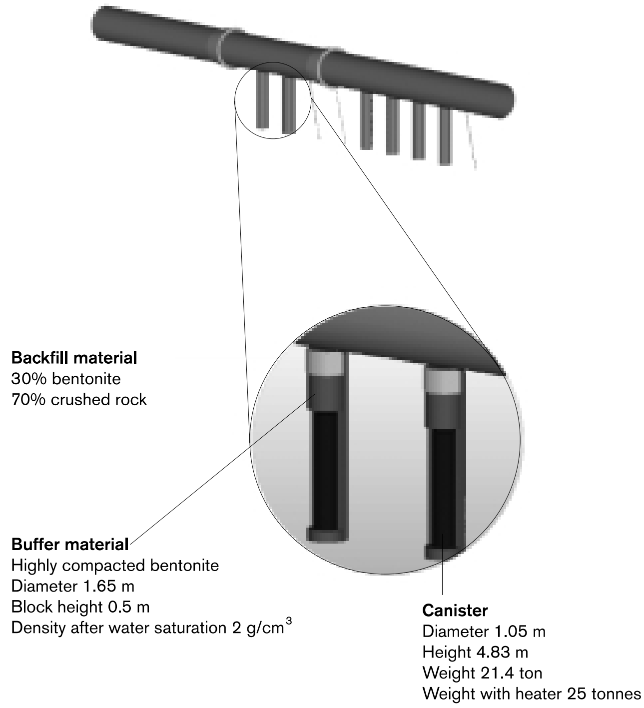


Figure 9-4. *Prototype repository at Äspö HRL.*

in vertical deposition holes is to place them horizontally in tunnels or in horizontal deposition holes in the tunnel wall. Such tests are being considered but have not yet been decided on, see section 7.4.2.

Handling of long-lived LILW will be very similar to the handling that takes place today in SFR. A special demonstration project for long-lived LILW is therefore not necessary. The experience from SFR is quite sufficient.

LOT

Research project at the Äspö HRL. The purpose is to study the long-term behaviour of buffer material in contact with the rock and the copper canister

LOT is a project for testing how the buffer material works in a deposition hole, and above all what the effects of heating are. An initial phase has already been carried out. Two vertical four-metre-deep boreholes with a diameter of about 300 mm were drilled in the Äspö HRL and filled with compacted bentonite and a heater in the middle. The tests lasted over 15 months, during which time temperature, pressure and thermal conductivity were measured. The temperature reached a maximum of 90°C in one hole and 130°C in the other. Samples of the bentonite were taken and sent to analysis, see Figure 9-6. Another four holes are planned, where the tests will last five and ten years, perhaps up to 20 years.

Special experiments are planned to determine how gas penetrates through a bentonite buffer. This has been tried in laboratories and calculation models have been developed. We will now see whether the calculations are accurate when the experiments are performed on a full scale down in the rock.

Natural analogues

Natural analogues

Examples from nature of materials and processes in the repository

The repository is supposed to protect the canisters for a very long time – up to hundreds of thousands of years. If the waste nevertheless comes into contact with the groundwater, dissolution is supposed to proceed very slowly, the buffer is supposed to limit the release of radionuclides, and the rock is also supposed to act as a barrier against the transport of radionuclides. Moreover, the barriers – poorly soluble fuel, canister, buffer and rock – must retain their properties over a long period of time. It is not possible to conduct experiments for such long times, which is the main reason to search for models in nature, known as natural analogues. SKB has been involved in a large number of such investigations since the early 1980s.

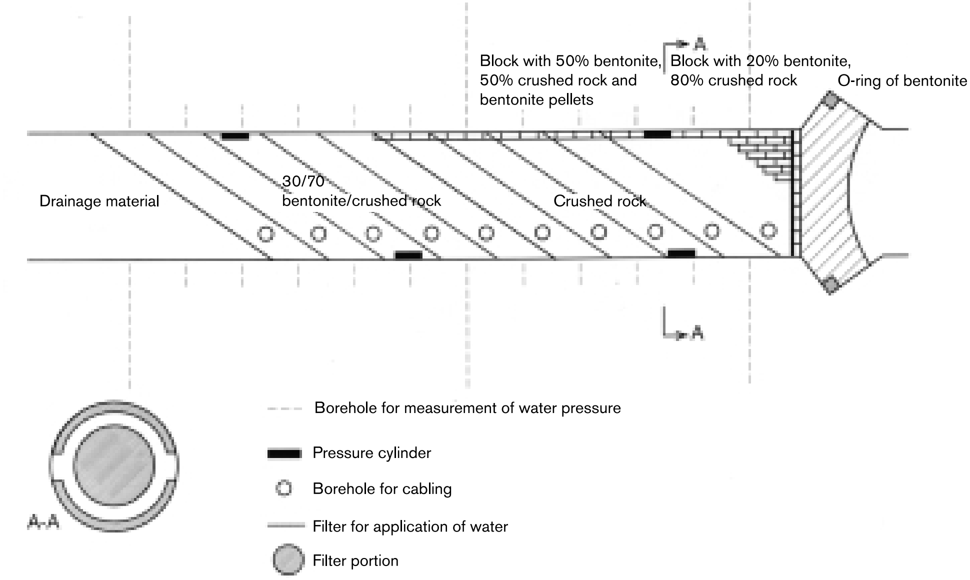


Figure 9-5. *Backfilling and plugging.*

The interest in natural analogues is international. It is common for nuclear waste organizations from several countries to pool their efforts and launch joint projects to study the most interesting analogues. The advantages of such an approach lie not only in sharing the work and the costs, but also in the fact that more researchers are given an opportunity to participate. Many participants with different backgrounds offer differing interpretations and viewpoints, which in turn leads to a critical evaluation and reduces the risk of hasty conclusions. Three big analogue projects in which SKB has participated and which are now concluded are Poços de Caldas (Brazil), Cigar Lake (Canada) and Maqarin (Jordan). The first two analogues consist of uranium-containing ore deposits and have taught us a great deal about the importance of oxidation in the near field around the waste. Maqarin is unique in the world due to its hyperalkaline springs. The water in the springs resembles pore water in concrete, providing a chemical analogue to wet concrete in a repository. In all three analogues we sampled water to see if it contained colloids and microbes. It has also been possible to test some of the calculations models used in the safety assessment. Examples of models that have been tested are those for:

- radionuclide solubility,
- decomposition of water due to radiation, known as radiolysis,
- water flow and solute transport,
- weathering of minerals.

At present, SKB is involved in two major international analogue projects: the Oklo and Palmottu projects. The first project is investigating the traces of the natural reactors that once existed in Oklo in Gabon, Africa, two billion years ago, while the other is studying a uranium ore deposit in Finland. In both cases, comparisons are made with spent fuel. Furthermore, both projects are being supported by the EU and are joint European research projects. The goal, as before, is to test the models used to make calculations in the safety assessment. Oklo offers unique opportunities in this respect. Oklo is the only known example of a site with natural nuclear reactors. The spent "reactor fuel" has been left in place so that we can study its remains. After such a long time, the primarily formed radionuclides have decayed and what we see are stable substances or extremely long-lived daughter nuclides (such as U-235, a residue of decayed Pu-239).

Hyperalkaline water

Water with a very high pH

Natural nuclear reactors at Oklo, Gabon

Daughter nuclide

The nuclide formed by radioactive decay of another radionuclide (the mother nuclide)

Figure 9-6. *The LOT test.*

The uranium ore in Palmottu is less exotic in all respects, but the very fact that it is located in the same shield region and with otherwise similar conditions as SKB's planned deep repository makes Palmottu particularly interesting.

Programmes and goals are just as important for analogue studies as for any other project, but a lot has to do with "making the most of what nature offers". One can never be sure whether the outcome of an analogue study will be sufficiently conclusive to be useful. Often it can be advantageous to conduct slightly narrower investigations, or at least to begin at that end. SKB has previously conducted such smaller-scope studies of e.g. uranium ore, bentonite and concrete. The goal has been to see how these materials change with time. New studies of a similar kind are under way, such as:

- Analysis of 90-year-old concrete from a water tank in Uppsala Castle.
- Investigations of a copper deposit in Hyrkkölä (pure metallic copper).
- Studies of bentonite samples.

The two EU projects in Oklo and Palmottu extend until 1999. What will happen after that will largely depend on the results of the investigations. One complication is that the mine in Oklo will be closed, so it probably won't be possible to continue sampling there after 1998.

Palaeogeohydrology

Palaeogeo-hydrology

Study of the composition and flow of groundwater during different geological epochs (history)

The traces of the hydrogeological conditions that previously prevailed in Sweden and other countries give an idea of what variations in water flows can be expected to occur in the future. It can also be seen what an ice age would entail and how it would affect the water flow down in the rock.

SKB has commissioned the University of Edinburgh to develop a calculation model of a continental ice sheet. With the aid of the model it is possible to simulate the advance and retreat of a continental ice sheet at a given place. The calculations provide information on the thickness of the ice at different times, the meltwater flow, the permafrost depth and the water pressure under the ice. This can be of assistance in future safety assessments when a good description is needed of *how* an ice age progresses. But it is much more difficult to predict *when* an ice age will occur in the future – if at all.

Due to the fact that available climate models are uncertain in their predictions of the future climate on earth, predictions of future ice ages are also uncertain. The points in time at which future cold periods will occur can be calculated with reasonable certainty, but it is difficult to determine which of these cold periods will give rise to a continuous ice sheet extending over most of Sweden and thereby over a repository site. It cannot be said with certainty today whether southern or central Sweden will be covered with ice at all in the next 100,000 years.

SKB is participating in two EU projects, PAGEPA and EQUIP. Within PAGEPA, the calculation models for groundwater chemistry and flow are being tested to see if they can be used to predict future changes. The testing involves using the models to perform calculations for the past, when the outcome is known. The measurement results needed for this have mainly been obtained from the Äspö HRL.

PAGEPA and EQUIP

PAGEPA = PAelaeohydrogeology and GEoforecasting for Performance Assessment

EQUIP = Evidence from Quaternary Infills for Palaeohydrogeology

Two research projects supported by the EU that study how the composition and flow of the groundwater have varied with time

Within the EU project EQUIP, the chemical traces left by earlier groundwaters in the fracture-filling minerals are being studied. The focus has been on the mineral calcite, since the shape of the calcite crystals shows what the composition of the water was when the crystals were formed, i.e. whether it was saltier than the groundwater is today. By determining the age of the fracture-filling minerals, it can be determined what the salinity of the groundwater at the sampling site has been at different times.

Deep drilling at Laxemar

SKB has had a vertical hole drilled in the rock down to a depth of about 1,700 metres at Laxemar, about two kilometres from Äspö. The drilling was carried out in 1992 for the purpose of testing the technique for drilling to great depths. We also wanted to obtain a drill core that describes the rock all the way, where no pieces are missing. This we succeeded in doing. Different types of equipment for measuring and sampling groundwater, for example, have since been tested in the borehole.

The results of the measurements and the analyses have increased our knowledge of the rock and the groundwater at great depths. No extensive investigations are planned during the coming three-year period, but water pressure meters will be installed at different levels, and it will also be possible to take more water samples to see if anything is changing.

9.4 Research on alternative methods

SKB's main task is to manage and dispose of the nuclear fuel waste in a safe manner (Section 10 of the Nuclear Activities Act). We also have a responsibility to follow and participate in the development of various alternative methods for managing and disposing of spent nuclear fuel, and to evaluate how these methods can affect long-term disposal.

Partitioning and transmutation (P&T)

The purpose of transmutation is to greatly reduce the quantity of long-lived radionuclides that have to be disposed of. Transmutation has come back into the focus of interest in the past decade. In the long term, transmutation could

Transmutation

Conversion of one element to another/other element(s) by bombarding it with neutrons in a nuclear reactor

contribute to the management of the nuclear fuel waste. A prerequisite for transmutation is that the spent nuclear fuel is reprocessed so that the long-lived radionuclides are separated from uranium, among other substances. Transmutation will never be able to replace the need for a deep repository completely. At best, it can reduce the quantity of long-lived substances in the waste, at the same time as the remaining energy content in the spent fuel is recovered. Partitioning technology requires extensive research and development before it can be ready for industrial application.

Goals and work strategy for the period 1999-2004

The goals of SKB's research and development on partitioning and transmutation of long-lived radionuclides are:

- to examine how this technology is being developed and how it will affect waste streams from nuclear facilities and the nuclide content of the waste,
- to determine whether, and if so how and when, this can be utilized to simplify, improve or develop a system for final disposal of the nuclear fuel waste from the Swedish NPPs.

Information is being gathered continuously according to annual activity plans. Overall assessments are made before important decisions in the nuclear waste programme. Thus, according to the requirements on alternative methods reporting, an assessment of P&T methods is to be included in the supporting documentation for decisions on the siting of the encapsulation plant and the deep repository. An overall assessment will also be made in conjunction with the evaluation following the initial stage of deposition of encapsulated nuclear fuel in the deep repository.

Accelerator-driven transmutation is currently the alternative line of development for P&T that is attracting the greatest interest both in Sweden and in a number of other countries. The development of such plants is very costly and heavily dependent on international collaboration. A number of fundamental technical questions need to be further cleared up by research before major projects with accelerator-driven transmutation can be started. In view of the

Proton

Nucleus of the hydrogen atom - has a positive unit charge

Neutron

Neutral/uncharged particle with the same weight as a proton. Atomic nuclei are made up of protons and neutrons

Reactor

In this context a nuclear reactor in which nuclear fission releases nuclear energy

Accelerator

Accelerates charged particles (protons, electrons and ions) to high energy states

Accelerator-driven transmutation

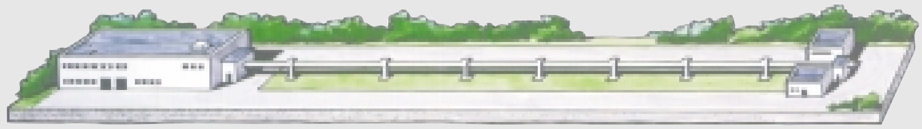
Transmutation which occurs in an accelerator-driven subcritical reactor

Nuclear fission in different reactors

Nuclear fission is caused by neutrons. In a **thermal reactor** the neutrons are slowed down by a moderator (of light atoms) to low (thermal) energy before the collisions that lead to nuclear fission occur. Sweden's ordinary light-water reactors are thermal reactors. They are cooled by water.

In a **fast reactor** the neutrons have a high energy (speed) when they collide with the fissionable atomic nuclei (uranium or plutonium). Fast reactors exist in Russia and France, where they are cooled with liquid sodium.

In existing reactors, nuclear fission takes place in a self-sustaining chain reaction: In each nuclear fission event, enough neutrons are formed to split another nucleus. The reactor is said to be critical when such a chain reaction is taking place. In a subcritical reactor, a chain reaction cannot occur - instead neutrons must be supplied from the outside. These neutrons are generated by a neutron source, which can be driven by an accelerator: **accelerator-driven subcritical reactor**.



development situation, the resources needed and relevant energy policy decisions in Sweden, we do not deem it prudent for us to initiate major development projects.

SKB intends to continue conducting domestic research at universities and institutes of technology with roughly the current scope. The primary purpose of the research should be to help to clarify fundamental technical questions pertaining to partitioning and transmutation. Particular emphasis should be placed on questions relating to safety, materials, process design and the composition of the waste streams. In this way domestic competence is created and a knowledge bank is built up to permit assessment of the prospects and characteristics of systems for partitioning and transmutation. The work will continue to be pursued in close contact with foreign research in the field. We are also open to the possibility of participating in an appropriate fashion in any international projects – particularly EU projects – that may be launched.

SKB will continue to conduct research on transmutation

Assessment of the future for partitioning and transmutation (P&T)

There is considerable international agreement among organizations and experts that a successful development of P&T will not eliminate the need for a deep repository. It may, on the other hand, change the design premises for the deep repository and its barriers, and greatly reduce the quantity of long-lived radionuclides that have to be deposited in the deep repository.

The substances which make the greatest contribution to the long-lived radiotoxicity of the spent nuclear fuel are the so-called "transuranics" or transuranic elements, i.e. mainly plutonium but also neptunium, americium and curium. A tonne of spent nuclear fuel contains approximately ten kg of plutonium and a total of about 1 kg of the three other transuranics. In time another 1 kg or more of plutonium is converted to americium and then to neptunium. Long-lived fission products and activation products such as technetium -99, iodine -129 and carbon -14 have much less radiotoxicity but are on the other hand more mobile in the rock.

Transuranic elements comprise a subgroup of the actinides which come after uranium in the periodic table, i.e. neptunium, plutonium, americium, curium, etc. In addition to the transuranics, the actinides also include uranium, protactinium, thorium and actinium. These are not transuranics because they come before uranium in the periodic table.

It is possible to carry out P&T, but it is too early to determine if such waste treatment has safety-related advantages compared with current plans for management of spent nuclear fuel and high-level waste. Neutrons from thermal reactors, fast reactors and accelerator-driven subcritical reactors can be utilized for transmutation of long-lived radionuclides. Thermal reactors and fast reactors have been built and operated with good experience for a long time. Accelerator-driven reactors are still on the drawing board. In a comparison of the alternatives, it is agreed today that transmutation in reactor types with fast (high-energy) neutrons has advantages in terms of reduction of the total quantity of heavier transuranics. A possible development is to utilize composite systems where each type of neutron source has a specific task. In such systems, the special properties of an accelerator-driven system are utilized to achieve an efficient transmutation of neptunium, americium and possibly curium, while ordinary nuclear reactors are used for energy production and plutonium burning.

Regardless of which type of system is ultimately used, it can be said as a rule of thumb that three to four reactors with fast neutrons (fast reactors and/or accelerator-driven reactors) are needed to transmute waste from the Swedish light-water reactors.

Development of P&T entails development of new nuclear technology and requires considerable resources and time. Large national programmes are being conducted in France and Japan. Under the terms of a law from 1991, the French are aiming at an interim goal in 2006. The costs of the programme are reported to be USD 600 million over 15 years.

The Japanese have not stipulated any timetable for their programme. The costs are in the order of magnitude of tens of millions of US dollars per year.

In the USA, the Los Alamos National Laboratory has proposed to begin with a five-year development project aimed at accelerator-driven transmutation. The cost is reported to be about USD 115 million. The ambition is to continue after this with a half-scale demonstration plant.

Within the EU there are proposals to increase funding of the development of accelerator-driven transmutation based on ideas put forth by Carlo Rubbia, the Nobel Prize laureate in physics at CERN.

CERN

European organization for research on nuclear physics and elementary particle physics with headquarters and large laboratories in Geneva.

These programmes are, however, just the beginning of the development work leading slowly up to the mandatory large-scale verification experiments. The successful development and application of P&T will also require a modification of the entire nuclear fuel cycle with respect to recovered uranium. Success in this effort will require extensive international cooperation. One opportunity for Sweden to participate in such cooperation is within the EU.

The costs of P&T are of course impossible to calculate with any certainty before it has been decided which kind of plant will be used. In the USA it has been calculated that plants for accelerator-driven transmutation of 70,000 tonnes of spent nuclear fuel from the approximately 100 American light-water reactors would require a total investment of about SEK 320 billion plus nearly SEK ten billion per year for operation during a period of 65 years – for a total of nearly SEK 1,000 billion in the space of about 65 years, not counting development costs. During this time the quantity of transuranic elements would decrease from approximately 600 tonnes to less than one tonne. At the same time, approximately 4,000 TWh of electric power would be obtained, worth about SEK 0.25 per kilowatt-hour or a total of around SEK 1,000 billion. It is uncertain how the deep repository costs would enter into this cost calculation. What is clear, however, is that the time needed for research and development, and then for transmutation of long-lived radionuclides from existing light-water reactors, is on the order of 100 years or more.

The development of new nuclear technology may also have the goal of more efficiently utilizing the energy content in the uranium extracted from the earth's crust. In this case, transmutation may be an interesting and important "by-product" that will considerably influence the future management of the spent nuclear fuel.

Transmutation requires a long-range nuclear waste programme

Transmutation instead of direct disposal would entail a further reduction of a relatively small, perhaps only hypothetical, risk far into the future. But on the other hand, the risk of exposure in the present or in the near future would increase appreciably due to a great increase in the handling of short-lived radioactive materials. This is an important question that requires further investigation.

The prospects for an application of P&T differ between different countries. The countries that reprocess their fuel today – e.g. Belgium, France, Japan, Switzerland, the UK and Germany – have already taken the first necessary step of separating residual uranium and plutonium. Other countries that have decided in favour of direct disposal – e.g. Finland, Spain, Switzerland and the USA – must in that case abandon this strategy. Development and application of P&T is, with a view towards time and costs, much more likely in a scenario with continued use, renewal and possible expansion of nuclear energy than in one where nuclear energy is abandoned.

In the Swedish scenario with a legislated decision not to build new nuclear power plants, a future domestic application of P&T would require a reversal of this decision. It would be unreasonably uneconomical to build a plant for P&T without making use of the energy generated in the transmutation process. Another possible future alternative would be to "purchase" P&T services at foreign plants and then "only" dispose of the waste.

Since the continued education of highly qualified personnel is required as long as the country has nuclear power plants, research and development on P&T offers a good way to attract new students and researchers to study subjects in the nuclear power field.

There is a broad scientific conviction that present-day types of fuel cycles in combination with planned waste management and geologic repositories will offer adequate protection for humanity for all foreseeable future time. At the same time, however, there is considerable interest in investigating whether a further reduction of the future potential hazard of the waste can be achieved by P&T and at what cost this can be accomplished. The strength of a P&T process would be that it would also drastically reduce the hypothetically possible future consequences of unforeseen events. On the other hand, a broad commitment to the development of P&T processes will obscure the fact that the future risks posed by a well-executed deep repository are already deemed to be very small.

Deep holes

The alternative of depositing canisters of spent fuel in boreholes several thousand metres deep was compared with the KBS-3 method in the PASS project, published in 1992. It proved to be difficult to judge the safety of the deep holes method. To be sure, a deeper geologic disposal could make the rock a more effective barrier, but conditions at great depth are not as well understood as those closer to the ground surface. To be able to deposit canisters of fuel in boreholes at a depth of between two and four kilometres it is necessary to be familiar with the properties of the bedrock down to at least five kilometres. Seismic measurements reach very deep, but boreholes deeper than one kilometre are unusual, and such boreholes are needed to make detailed measurements and take samples of, for example, the composition of the water.

Seismic measurements

Geophysical measurements with sound waves to study the properties and structure of the rock

At great depth in the rock, temperature, rock stresses and water pressure increase, the groundwater generally gets saltier and the water flow decreases. This can entail both advantages and disadvantages for a repository. Higher pressure, temperature and salinity increase the stresses on the materials in the canister and the backfill, while high density due to the salt makes the groundwater heavy and nearly immobile.

Difficult to assess the safety of disposal in very deep holes

A study was recently completed to ascertain the geological conditions at depths down to about five kilometres /7-15/. The report in question summarizes the knowledge that has been obtained from investigations in very deep boreholes, for example in Russia. The necessary conditions for very deep disposal are dealt with in the report, but the authors do not draw any conclusions as to whether this is sensible and feasible. This would require a deeper analysis with a focus on safety – something which SKB is currently planning.

10 Decommissioning

When a nuclear power plant is taken out of service, certain parts of it are radioactive. Decommissioning and dismantling must therefore be carried out in a controlled manner with due consideration given to both radiation protection and conventional industrial safety. Parts of the decommissioning waste must be managed and disposed of as radioactive waste. The same applies to CLAB and the encapsulation plant when they are taken out of service.

The timetable for the decommissioning of the Swedish nuclear power plants is not yet clear. Several years before decommissioning commences, a project group will be organized to plan the decommissioning work in detail. The necessary knowledge concerning e.g. dismantling methods, classification of waste and transportation systems must be available at this time.

10.1 Experience of decommissioning

A number of small research reactors and a few small and medium-sized nuclear power plants have already been decommissioned at various places in the world. Additional nuclear power plants are currently being dismantled. Other reactors that have been taken out of service are being "mothballed" for a period of time before dismantling begins.

Experience of decommissioning in Sweden is limited to the decommissioning of the R1 research reactor in Stockholm and some smaller test facilities at Studsvik. Considerable experience of a similar kind has, however, been obtained from the thorough decontamination and rebuilding of Oskarshamn 1, the steam generator replacements at Ringhals 2 and Ringhals 3, and from other repair and rebuilding jobs at the nuclear power stations.

Experience to date and numerous studies show that methods for decommissioning and dismantling nuclear power plants are available today. In many countries, the biggest obstacle to decommissioning is the fact that final repositories for the waste have not yet been built or that the existing repositories are not capable of accommodating the decommissioning waste.

10.2 Decommissioning procedure

When a nuclear power plant has been taken out of service, after a period of time the site should be restored (remediated) so that it can be used without radiological restrictions. This must be done in such a manner that neither the personnel engaged in the decommissioning and dismantling work nor the general public are exposed to unnecessary irradiation.

The design and licensing process for final disposal of the radioactive waste from decommissioning requires coordinated planning for the whole country. Such planning has advantages when it comes to such aspects as availability of special equipment and specially trained personnel, and opportunities for experience feedback. It is assumed that decommissioning will not commence before 2010.

The power utilities bear principal responsibility for decommissioning

Decommissioning will be planned and executed in cooperation between the power utilities and SKB. The power utilities bear principal responsibility for planning and execution of the dismantling work, as well as for treatment of the waste. Their responsibility also includes deciding which strategy should be applied regarding the time for dismantling, i.e. whether a reactor is to be dismantled immediately or mothballed. The power utilities can draw on SKB as a resource in this work.

SKB is responsible for the radioactive decommissioning waste

SKB is responsible for management and disposal of the radioactive waste that arises during decommissioning. For this, the transportation system must be modified and SFR expanded. Parts of the waste, e.g. the core components, will be disposed of in the deep repository and may need to be stored for a time prior to that in CLAB. SKB will ensure, in consultation with the power utilities, that the waste is treated and packaged in a manner suitable for final disposal.

The timetable is affected by:

- availability of personnel
- land use after decommissioning
- radiation protection
- politics

The timetable for decommissioning of the Swedish nuclear power plants has not yet been finalized. It will be influenced by a number of different factors, the most important of which are availability of personnel familiar with the plants and what other activity is planned on the site. Radiation protection aspects and, not least, general political aspects may also influence the timetable.

The manner in which decommissioning and dismantling of the Swedish nuclear power plants is planned to proceed is described in greater detail in /10-1/. Decommissioning can be commenced approximately one year after the last reactor has been shut down at a nuclear power station. In the case of immediate dismantling, personnel familiar with the plant will be on hand. In the case of deferred dismantling, the radiation levels are lower, which simplifies dismantling. Deferred dismantling may also be the preferred option if the dismantling work disrupts other activities. The IAEA has defined three stages in decommissioning /10-2/:

IAEA
International Atomic Energy Agency

- Stage 1: Fuel and water have been removed from the reactor and the control systems have been disconnected. Access to the plant is restricted and the plant is kept under surveillance and inspected periodically.
- Stage 2: Most of the components containing radioactive materials have been assembled in a contained area in the plant or its vicinity. The area is sealed, which means that less surveillance is required than in stage 1. It is desirable that periodic inspection should continue.
- Stage 3: All radioactive materials have been removed and the area has been released for unrestricted use. As an alternative to free release immediately after the conclusion of decommissioning, some waste can be left in a shallow ground repository on the site. Such a repository requires surveillance for approximately 50 years.

After the plant has been taken out of service the dismantling work can be deferred (by between 30 and 50 years). In case of deferred dismantlement, all three stages are applied. If dismantlement is begun within a few years of shutdown, it is natural to proceed directly from stage 1 to stage 3.

Decommissioning gives rise to a large quantity of low-level material that could be released for unrestricted use, possibly after decontamination. There is some experience of such free release at the nuclear power plants. However, the low limits for free release mean that measurement and classification are very labour-consuming. Before decommissioning is commenced, it is therefore essential that rules and methods for free release be developed so that classification can be done routinely. It is also important to be able to measure low activity levels. Discussions are under way within the IAEA and the EU on activity levels for free release of contaminated material.

In order for the decommissioning work to be carried out in an efficient manner, it is essential that some administrative questions also be cleared up, for example what type of licence is needed and what accounting is required by the regulatory authorities. This work lies within the sphere of responsibility of the authorities. SSI and SKI are currently studying such matters.

10.3 Current state of knowledge

10.3.1 Sweden

A comprehensive study of technology and costs for decommissioning and dismantling the Swedish nuclear power plants is reported in /10-1/. The conclusion of the study is that decommissioning is not expected to entail any major technical problems. Most of the technology that is needed is already available and is used routinely in maintenance, repair and rebuilding work at the nuclear power plants. Special equipment has to be developed to dismantle the reactor pressure vessel and to demolish heavy concrete structures, however, although some experience of such work is available from ongoing decommissioning projects in other countries.

Decommissioning can largely be carried out with available technology

The calculated costs for decommissioning the Swedish nuclear power plants are low by international standards. This is in part attributable to the efficient system that has been developed for transportation and final disposal of nuclear waste in Sweden. The system enables large components to be handled without the need for extensive segmentation.

A number of major reconstructions have been carried out at the nuclear power plants in recent years. One example is the steam generator replacement at Ringhals 3, see Figure 10-1. Experience from such work will prove valuable in the future dismantling work.

Experience from reconstructions at the Swedish NPP's is valuable

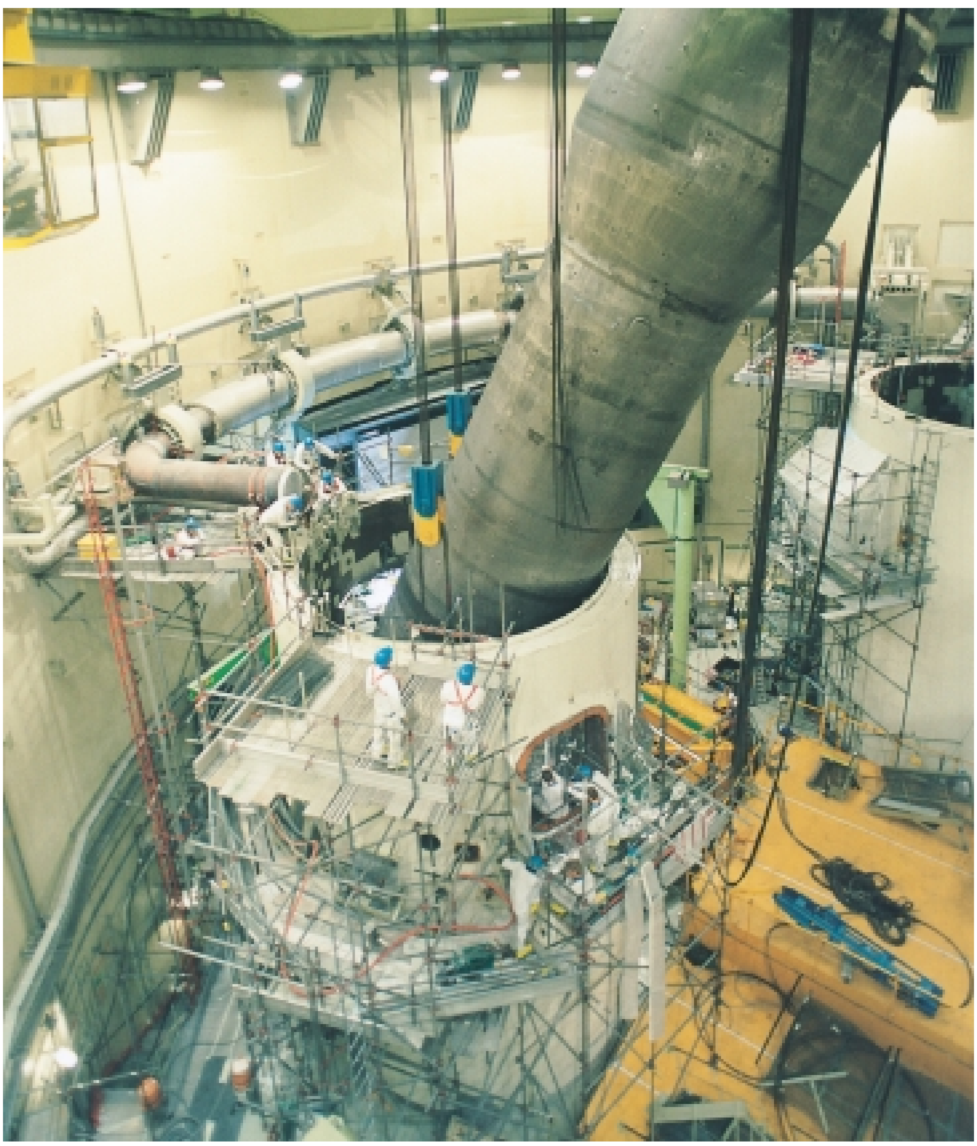


Figure 10-1. *Replacement of steam generator in Ringhals 3.*

SKB has studied the possibility of removing and transporting the reactor pressure vessels intact, as an alternative to segmenting them before they are emplaced in SFR. This method can save radiation dose and costs and ought to be considered as an option when decommissioning is planned in detail.

10.3.2 Other countries

There is great international experience of decommissioning

More than 20 reactors have been decommissioned to stage 3 in different parts of the world. In addition, a large number of plants have been taken out of service and decommissioned to stage 1 or 2. Most decommissionings have so far in-volved experimental reactors or small power reactors. It is only in recent years that medium-sized and large reactors have been taken out of service. Some development of dismantling methods is taking place in parallel with actual decommissioning projects. Some examples of experience of decommissionings in other countries are given below.

Decommissionings or dismantlements of a number of commercial reactors are under way in the USA, for example Trojan, Rancho Seco, Maine Yankee and Fort St. Vrain. In Germany, Gundremmingen A, Kahl and a number of small reactors are currently being dismantled. Moreover, planning is under way for the decommissioning of reactors at Greifswald and Würgassen. Some reactors, for example Lingen, have been placed in stage 2 for later dismantlement.

In France, two water-cooled reactors and all Magnox reactors have been taken out of service. They will be transferred to stage 2. However, a discussion is under way concerning the possibility of dismantling a reactor in the near future in order to demonstrate the technology. Most of the Magnox reactors in England have also been taken out of service. Work is in progress to transfer them to stage 2. Dismantlement is planned to take place in about 100 years.

10.3.3 OECD/NEA

OECD/NEA
Nuclear Energy Agency within the OECD

A special programme has been organized within the OECD/NEA for an exchange of information and experience within the decommissioning field. Most major decommissioning projects in the world are included in this programme. At present the programme includes some 35 projects in 13 countries. Nineteen of the projects aim at complete decommissioning and dismantlement to stage 3. Within the cooperative programme there is an exchange of experience from day-to-day activities, as well as more extensive discussions of technical questions. Examples of such questions are melting of metallic waste, monitoring methods for low-level waste, removal of asbestos and methodology for cost estimates and cost accounting. SKB is in charge of coordinating the OECD/NEA programme and can in this way follow the technical aspects of the different projects.

Experience from the first ten years has been compiled in a report that contains both straight descriptions of the projects and a thorough analysis of status and development needs for different technical areas /10-3/.

The areas discussed are:

- assessment of activity inventories,
- cutting techniques,
- remote operation,
- decontamination,
- melting,
- radioactive waste management,
- health and safety.

In most cases the development need has to do with translating experience from tried-and-tested methods to applications on an industrial scale, as well as gaining experience from this. No area has been identified where fundamental development is needed.

The projects that are of particular interest for Swedish purposes are Shippingport (USA), JPDR (Japan), Niederaichbach (Germany) and BR-3 (Belgium). The decommissioning and dismantlement of Shippingport is concluded. Of particular interest was the fact that the reactor pressure vessel was lifted out intact and transported by barge to the final disposal site. The decommissionings of JPDR and Niederaichbach are also concluded. In both cases the reactor pressure vessels were segmented using remote-controlled machines. In the JPDR project, thorough trials and development of different dismantlement methods have been carried out. Segmentation of the reactor pressure vessel after thorough decontamination is being studied for BR-3 as well.

10.3.4 EU

The EU is sponsoring studies of

- dismantling techniques
- activity content
- waste management

The EU has had a research programme within the field of decommissioning since 1979. So far the studies have primarily concerned different dismantling techniques as well as questions pertaining to activity content and waste management /10-5/. The following research areas have been covered:

- long-term integrity of buildings and systems,
- decontamination,
- dismantling techniques,
- treatment of specific waste materials (steel, concrete and graphite),
- large waste containers,
- estimation of waste quantities.

Work is also under way to formulate guidelines for decommissioning.
A compre-hensive account of the results achieved is given in /10-5/.

The EU has concluded that decommissioning is a mature technology

In the recently concluded third five-year programme, the emphasis has shifted towards application and testing of different dismantling techniques under actual conditions. The four decommissioning projects included in the programme are the reactors Windscale AGR (UK), Gundremmingen A (Germany) and BR-3 (Belgium), and the reprocessing plant AT-1 (France). In the planning of the fourth programme, the EU has concluded that decommissioning is a mature technology which can be based on commercially available methods. The scope of the research has therefore been reduced considerably.

10.3.5 IAEA

Work is under way within the IAEA aimed at summarizing the state of knowledge within the different technical areas and formulating recommendations and advice for future applications for licences for decommissioning. The IAEA also has a coordinated R&D programme within the decommissioning field. SKB has participated in this programme with a study of the handling of an intact reactor pressure vessel.

10.4 Programme for future work

The overall goals of SKB's activities in the decommissioning field are to:

- perform cost calculations as a basis for determining the need for allocations to a sinking fund for future decommissioning costs,
- ensure that knowledge and technology for decommissioning are developed in good time before detailed planning of the decommissioning work is to begin,
- ensure that the waste from decommissioning is properly managed, transported and disposed of.

To achieve these goals it is important to keep track of international developments. It is also important to systematically assimilate experience from repair and rebuilding projects at nuclear power plants and other nuclear installations. Certain special studies and tests may also need to be done.

Most of the methods that are needed are already available and are being used in Sweden, but some equipment needs to be modified and developed. Since a great deal of development work is currently being done abroad, there is no justification for starting any large Swedish development efforts during the coming six-year period. The studies that have been made of decommissioning of the Swedish nuclear power plants have indicated some areas where early measures are warranted /10-1/. The most important subjects for study are:

- the feasibility of managing and disposing of an intact reactor vessel,
- transportation and final disposal of other large components,
- technology for segmentation of reactor internals,
- technology for demolition of the biological shield,
- management and disposal of contaminated asbestos insulation,
- methods and equipment for activity measurement of the waste for unrestricted release, or simpler disposal,
- decontamination for unrestricted release,
- volume reduction of the waste by means of compaction or melting.

SFR needs to be expanded to receive the decommissioning waste

Before the nuclear power plants are decommissioned, SFR must also be expanded to receive the decommissioning waste. The expansion requires a new licence. Since the decommissioning waste in many respects resembles waste from the operation period, experience from SFR can serve as a basis for the design. The time from preliminary planning and design to a finished facility has been estimated to be about seven years, which means that the expansion of SFR will not begin until a few years into the 21st century.

References

Chapter 1

1-1 SKB
Plan 98. Costs for management of the radioactive waste from nuclear power production
Swedish Nuclear Fuel and Waste Management Co, 1998
SKB TR 98-07

1-2 Hedin A
Spent fuel – how dangerous is it? A report from the project "Description of risk"
SKB TR 97-13, Swedish Nuclear Fuel and Waste Management Co, 1997

1-3 Eriksson M
Test av det reformerade finansieringssystemet
Nucleus Nr 16, 2/1998, Swedish Nuclear Power Inspectorate, 1998

1-4 SSI
Remiss av föreskrifter om slutligt omhändertagande av använt kärnbränsle eller kärnavfall
SSI Dnr 042/942/97, 1997-04-01, Swedish Radiation Protection Institute, 1997

1-5 SKI
Utgångspunkter för föreskrifter om säkerhet vid slutförvaring av använt kärnbränsle m m
SKI Promemoria 97017, 1997-03-26, Swedish Nuclear Power Inspectorate, 1997

1-6 Statens offentliga utredningar
Spent fuel and radioactive waste
Report of the Aka Committee
SOU 1976:30, 31 and 41, 1976

1-7 Ekendahl A-M, Papp T
Alternativa metoder. Långsiktigt omhändertagande av kärnbränsleavfall
R-98-11, Swedish Nuclear Fuel and Waste Management Co, 1998

1-8 SKB
CLAB Etapp 2. Sammanfattande miljökonsekvensbeskrivning
CLAB Etapp 2 PR 97-05, Swedish Nuclear Fuel and Waste Management Co, 1997

Chapter 2

2-1 Swedish Environmental Protection Agency
Slutförvar för kvicksilver
Rapport 4752, Naturvårdsverkets Förlag, 1997

2-2 Söderman E
Kontrollerad långtidslagring i CLAB
R-98-17, Swedish Nuclear Fuel and Waste Management Co, 1997

2-3 Birgersson L, Grundfeldt B, Larsson A, Pers K
Konsekvenser av ett övergivet CLAB
R-98-18, Swedish Nuclear Fuel and Waste Management Co, 1997

2-4 SKB
Project on Alternative Systems Study (PASS)
Final report
Swedish Nuclear Fuel and Waste Management Co, 1992
SKB TR 93-04

2-5 **Thegerström C**
The Swedish Approach to Spent Fuel Disposal – Stepwise Implementation and the Role of Retrievability
In: Proc. of the 4th Int. Workshop on Design and Construction of Final Repositories
October 6–8, 1997, Lucerne, Switzerland, Nagra

2-6 **Svemar C**
Alternative Retrieval Methods Considered by SKB
In: Proc. of the 4th Int. Workshop on Design and Construction of Final Repositories
October 6–8, 1997, Lucerne, Switzerland, Nagra

2-7 **Eng T, Norberg E, Torbacke J, Jensen M**
Information, conservation and retrieval
SKB TR 96-18, Swedish Nuclear Fuel and Waste Management Co, 1996

2-8 **Statens offentliga utredningar**
Spent fuel and radioactive waste
Report of the Aka Committee
SOU 1976:30, 31 and 41, 1976

2-9 **SKBF/KBS**
Handling of spent nuclear fuel and final storage of vitrified high level reprocessing waste. Parts I–V. Projekt Kärnbränslesäkerhet
SKBF/KBS, 1977

2-10 **SKBF/KBS**
Handling and final storage of unreprocessed spent nuclear fuel
Parts I–II. Projekt Kärnbränslesäkerhet
SKBF/KBS, 1978

2-11 **SKBF/KBS**
Final storage of spent nuclear fuel – KBS-3. Parts I–IV
SKBF/KBS, 1983

2-12 **SKB**
R&D-Programme 86, Parts I–III. Handling and final disposal of nuclear waste. Programme for research, development and other measures.
Swedish Nuclear Fuel and Waste Management Co, 1986

2-13 **SKB**
Handling and final disposal of nuclear waste. Alternative disposal methods
Background report to R&D-Programme 86
Swedish Nuclear Fuel and Waste Management Co, 1986

2-14 **SKB**
R&D-Programme 89, Parts I–II. Handling and final disposal of nuclear waste. Programme for research, development and other measures
Swedish Nuclear Fuel and Waste Management Co, 1989

2-15 **SKB**
RD&D-Programme 92. Treatment and final disposal of nuclear waste
Programme for research, development, demonstration and other measures
Main report plus three background reports
Swedish Nuclear Fuel and Waste Management Co, 1992

2-16 **SKB**
SKB 91. Final disposal of spent nuclear fuel
Importance of the bedrock for safety
Swedish Nuclear Fuel and Waste Management Co, 1992
SKB TR 92-20

2-17 SKB
RD&D-Programme 92, Supplement. Treatment and final disposal of nuclear waste. Supplement to the 1992 programme in response to the Government decision of December 16, 1993.
Swedish Nuclear Fuel and Waste Management Co, 1994

2-18 SKB
RD&D-Programme 95. Treatment and final disposal of nuclear waste. Programme for encapsulation, deep geological disposal, and research, development and demonstration
Swedish Nuclear Fuel and Waste Management Co, 1995

Chapter 3

3-1 SKB
Systemredovisning av djupförvaring enligt KBS-3 metoden
R-98-10, Swedish Nuclear Fuel and Waste Management Co, 1998

3-2 Söderman E
Kontrollerad långtidslagring i CLAB
R-98-17, Swedish Nuclear Fuel and Waste Management Co, 1997

3-3 Birgersson L, Grundfeldt B, Larsson A, Pers K
Konsekvenser av ett övergivet CLAB
R-98-12, Swedish Nuclear Fuel and Waste Management Co, 1997

3-4 Gillin K
Säkerheten vid drift av inkapslingsanläggningen
R-98-18, Swedish Nuclear Fuel and Waste Management Co, 1998

3-5 Ekendahl A-M, Pettersson S
Säkerheten vid transport av inkapslat bränsle
R-98-14, Swedish Nuclear Fuel and Waste Management Co, 1998

3-6 Lönnerberg B, Pettersson S
Säkerheten vid drift av djupförvaret
R-98-13, Swedish Nuclear Fuel and Waste Management Co, 1998

3-7 SKBF/KBS
Final storage of spent nuclear fuel – KBS-3. Parts I–IV
SKBF/KBS, 1983

3-8 SKB
SKB 91. Final disposal of spent nuclear fuel
Importance of the bedrock for safety
SKB TR 92-20, Swedish Nuclear Fuel and Waste Management Co, 1992

3-9 SKI
SITE-94, Deep Repository Performance Assessment Project
SKI Report 96:35, Swedish Nuclear Power Inspectorate, 1996

Chapter 4

4-1 Hedin A
Spent fuel – how dangerous is it? A report from the project "Description of risk"
SKB TR 97-13, Swedish Nuclear Fuel and Waste Management Co, 1997

Chapter 6

6-1 **SKI**
SKI's evaluation of SKB's RD&D-Programme 95. Review report
SKI Report 96:57, Swedish Nuclear Power Inspectorate, 1996

6-2 **KASAM**
Nuclear waste – Disposal technology and site selection.
KASAM's review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D-Programme 95
SOU 1996:101, 1996

6-3 **Regeringsbeslut** angående FUD-program 92, kompletterande redovisning
Government decision 11, 1995-05-18

6-4 **Regeringsbeslut** angående FUD-program 95
Government decision 25, 1996-12-19

6-5 **MKB-forum i Kalmar län**
Projekt inkapsling. Planeringsrapport för miljökonsekvensbeskrivning
Dokument 1995-12-01

6-6 **SKB**
Förstudie Östhammar. Preliminär slutrapport
Swedish Nuclear Fuel and Waste Management Co, 1997

6-7 **SKB**
General Siting Study 95 – Siting of a deep repository for spent nuclear fuel
SKB TR 95-34, Swedish Nuclear Fuel and Waste Management Co, 1995

6-8 **SGU**
Översiktsstudie av Blekinge län: geologiska förutsättningar
R-98-22, Swedish Nuclear Fuel and Waste Management Co, 1998

6-9 **SGU**
Översiktsstudie av Kalmar län: geologiska förutsättningar
R-98-24, Swedish Nuclear Fuel and Waste Management Co, 1998

6-10 **SGU**
Översiktsstudie av Östergötlands län: geologiska förutsättningar
R-98-26, Swedish Nuclear Fuel and Waste Management Co, 1998

6-11 **SGU**
Översiktsstudie av Södermanlands län: geologiska förutsättningar
R-98-28, Swedish Nuclear Fuel and Waste Management Co, 1998

6-12 **SGU**
Översiktsstudie av Stockholms län: geologiska förutsättningar
R-98-30, Swedish Nuclear Fuel and Waste Management Co, 1998

6-13 **SGU**
Översiktsstudie av Uppsala län: geologiska förutsättningar
R-98-32, Swedish Nuclear Fuel and Waste Management Co, 1998

6-14 **SGU**
Översiktsstudie av Gävleborgs län: geologiska förutsättningar
R-98-34, Swedish Nuclear Fuel and Waste Management Co, 1998

6-15 **SGU**
Översiktsstudie av Västernorrlands län: geologiska förutsättningar
R-98-36, Swedish Nuclear Fuel and Waste Management Co, 1998

6-16 **SGU**
Översiktsstudie av Västerbottens län: geologiska förutsättningar
R-98-38, Swedish Nuclear Fuel and Waste Management Co, 1998

6-17 **SGU**
Översiktsstudie av Norrbottens län: geologiska förutsättningar
R-98-40, Swedish Nuclear Fuel and Waste Management Co, 1998

6-18 La Pointe P, Wallman P, Thomas A, Follin S
A methodology to estimate earthquake effects on fractures
intersecting canister holes
SKB TR 97-07, Swedish Nuclear Fuel and Waste Management Co, 1997

6-19 Leijon B
Nord-syd/Kust-inland. Generella skillnader i förutsättningar
för lokalisering av djupförvar mellan olika delar av Sverige
R-98-16, Swedish Nuclear Fuel and Waste Management Co, 1998

6-20 Hedin A
Spent fuel – how dangerous is it?
A report from the project "Description of risk"
SKB TR 97-13, Swedish Nuclear Fuel and Waste Management Co, 1997

6-21 SKB
Feasibility study for siting of a deep repository within the Storuman
municipality.
SKB TR 95-08, Swedish Nuclear Fuel and Waste Management Co, 1995

6-22 SKB
Feasibility study for siting of a deep repository within the Malå
municipality.
SKB TR 96-22, Swedish Nuclear Fuel and Waste Management Co, 1996

6-23 Drottz, Sjöberg B-M
Stämningar i Malå efter folkomröstningen 1997
PR D-98-03, Swedish Nuclear Fuel and Waste Management Co, 1998

6-24 Lidskog R (ed.)
Kommunen och kärnavfallet
Carlssons förlag, 1998

6-25 Vedung E, Olofsson P
Lokalsamhällets beslutsfattande om kärnavfallet – tre kommuner i norr
SKI-rapport 97:38, Swedish Nuclear Power Inspectorate, 1997

6-26 National Coordinator in the Nuclear Waste Field
Kampanj med kunskaper och känslor. Om kärnavfallsomröstningen
i Malå kommun 1997
Statens offentliga utredningar 1998:62, Ministry of the Environment, 1998

6-27 SKB
Förstudie Nyköping. Preliminär slutrapport.
Swedish Nuclear Fuel and Waste Management Co, 1997

6-28 Municipal Council, Oskarshamn Municipality
Sammanträdesprotokoll 1996-10-14.

6-29 SKB
Förstudie Oskarshamn. Program
R-97-07, Swedish Nuclear Fuel and Waste Management Co, 1997

6-30 Andersson J, Almén K-E, Ericsson L O, Fredriksson A, Karlsson F, Stanfors R, Ström A
Parameters of importance to determine during geoscientific site
investigation
SKB TR 98-02, Swedish Nuclear Fuel and Waste Management Co, 1998

6-31 Stanfors R, Erlström M, Markström I
Äspö HRL – Geoscientific evaluation 1997/1. Overview
of site characterization 1986–1995
SKB TR 97-02, Swedish Nuclear Fuel and Waste Management Co, 1997

6-32 Rhén I (ed), Bäckblom G (ed), Gustafson G, Stanfors R, Wikberg P
Äspö HRL – Geoscientific evaluation 1997/2. Results from
pre-investigations and detailed site characterization. Summary report
SKB TR 97-03, Swedish Nuclear Fuel and Waste Management Co, 1997

6-33 Rhén I (ed), Gustafson G, Stanfors R, Wikberg P
Äspö HRL – Geoscientific evaluation 1997/5
Models based on site characterization 1986–1995
SKB TR 97-06, Swedish Nuclear Fuel and Waste Management Co, 1997

6-34 Ahlbom K, Smellie J (ed)
Characterization of fracture zone 2. Finnsjön study site
Journal of Hydrology, Special issue, Vol. 126, Nos. 1-2, 1991

6-35 Fairhurst C, Gera F, Gnirk P, Gray M, Stillborg B
OECD/NEA International Stripa Project 1980–1992
Overview Volume 1. Executive Summary
Swedish Nuclear Fuel and Waste Management Co, 1993

6-36 Ekman L, Ludvigsson J-E
Project Deep Drilling KLX 02 – Phase 2 Lilla Laxemar, Oskarshamn
Scope of activities and results. Summary Report
TR (in prep.), Swedish Nuclear Fuel and Waste Management Co, 1998

6-37 Posiva OY
Slutförvarsanläggning för använt kärnbränsle
Program för miljökonsekvensbedömning 1998

6-38 Ström A, Almén K-E, Andersson J, Ericsson L O, Svemar C
Geovetenskapliga värderingsfaktorer och kriterier för platsutvärdering
Lägesredovisning
R-98-20, Swedish Nuclear Fuel and Waste Management Co, 1998

6-39 Rhén I (ed)
Granskning av utvärderings- och fältundersökningsmetoder
vid hydrauliska tester. HYDRIS-gruppens sammanfattning
PR D-95-014, Swedish Nuclear Fuel and Waste Management Co, 1995

Chapter 7

7-1 Werme L
Design premises for canister for spent nuclear fuel
SKB TR 98-08, Swedish Nuclear Fuel and Waste Management Co, 1998

7-2 Smart N, Rance A, Blackwood D
Corrosion aspects of the copper-steel/iron process canister:
Consequences of changing the material for the inner
container from carbon steel to cast iron
Inkapsling PR 97-04, Swedish Nuclear Fuel and
Waste Management Co, 1997

7-3 Andersson C-G
Utformning av en produktionsenhet för tillverkning av kapslar
för slutförvaring av använt kärnbränsle, Version 1
Inkapsling PR 97-05, Swedish Nuclear Fuel and
Waste Management Co, 1997

7-4 Burström M
Kopparmarknaden
Inkapsling PR 97-03, Swedish Nuclear Fuel and
Waste Management Co, 1996

7-5 SKB
Systemredovisning av djupförvaring enligt KBS-3 metoden
R-98-10, Swedish Nuclear Fuel and Waste Management Co, 1998

7-6 Gillin K
Säkerheten vid drift av inkapslingsanläggningen
R-98-12, Swedish Nuclear Fuel and Waste Management Co, 1998

7-7 Ekendahl A-M, Pettersson S
Säkerheten vid transport av inkapslat bränsle
R-98-14, Swedish Nuclear Fuel and Waste Management Co, 1998

7-8 Pettersson S, Svemar C
Anläggningsbeskrivning. Nedfart endast via schakt
AR 44-93-003, Swedish Nuclear Fuel and Waste Management Co, 1993

7-9 Pettersson S, Svemar C
Anläggningsbeskrivning. Nedfart via spiralramp och serviceschakt
AR 44-93-004, Swedish Nuclear Fuel and Waste Management Co, 1993

7-10 Pettersson S, Svemar C
Anläggningsbeskrivning. Nedfart via rak ramp
AR 44-93-005, Swedish Nuclear Fuel and Waste Management Co, 1993

7-11 Lönnerberg B, Pettersson S
Säkerheten vid drift av djupförvaret
R-98-13, Swedish Nuclear Fuel and Waste Management Co, 1998

7-12 SKB
Förstudie Östhammar. Preliminär slutrapport
Swedish Nuclear Fuel and Waste Management Co, 1997

7-13 SKB
Förstudie Nyköping. Preliminär slutrapport
Swedish Nuclear Fuel and Waste Management Co, 1997

7-14 SKB
Project on Alternative Systems Study (PASS)
Final report
SKB TR 93-04, Swedish Nuclear Fuel and Waste Management Co, 1992

7-15 Juhlin C, Wallroth T, Smellie J, Eliasson T, Ljunggren C, Leijon B, Beswick J
Very Deep Hole concept: Geoscientific appraisal of conditions at great depth
SKB TR 98-05, Swedish Nuclear Fuel and Waste Management Co, 1998

7-16 Jansson L, Nicklasson A, Jendenius H, Idoff M, Lindblom K, Bjerke E, Jansson P
Projekt JADE. Metod- och maskinbeskrivning av utrustning för deponering avkapsel i vertikalt deponeringshål
AR D-97-29, Swedish Nuclear Fuel and Waste Management Co, 1997

7-17 Huertas F, Santiago J L
The FEBEX Experiment, General Overview
In: Proc. of a cluster seminar on In-situ Testing in Underground Research Laboratories for Radioactive Waste Disposal
December 10–11, Alden Biesen, Belgium, Report EUR 18323 EN, European Commission, 1997

7-18 Israelsson J, Hakami E
Global thermomechanical effect from a KBS-3 type repository – Phase 3a: Multilevel Repository
PR D-97-10, Swedish Nuclear Fuel and Waste Management Co, 1997

7-19 Emsley S, Olsson O, Stenberg L, Alheid H-J, Falls S
ZEDEX – A study of damage and disturbance from tunnel excavation by blasting and tunnel boring
SKB TR 97-30, Swedish Nuclear Fuel and Waste Management Co, 1997

7-20 Autio J, Kirkkomäki T
Boring of full scale deposition holes using a novel dry blind boring method
SKB TR 96-21, Swedish Nuclear Fuel and Waste Management Co, 1996

7-21 Autio J
Characterization of the excavation disturbance caused by boring of the experimental full scale deposition holes in the Research Tunnel at Olkilouoto
SKB TR 97-24, Swedish Nuclear Fuel and Waste Management Co, 1997

7-22 Bodén A, Hässler L, Gustafson G, Lindblom U, Lagerblad B, Pusch R, Stille H
Injekteringsteknik. Kunskapsläge och utvecklingsbehov
PR D-97-04, Swedish Nuclear Fuel and Waste Management Co, 1997

7-23 Bodén A (ed.)
Projekt Injektering – Avrapportering av etapp 1
PR D-98-04, Swedish Nuclear Fuel and Waste Management Co, 1998

7-24 Gustafson G, Pusch R, Rhén I
Bedrock characterization as base for grouting design. Practical examples from Äspö HRL and the Stripa Project
AR D-96-002, Swedish Nuclear Fuel and Waste Management Co, 1996

7-25 Stille H, Olsson P
Summary of rock mechanical results from the construction of the Äspö Hard Rock Laboratory
PR HRL-96-07, Swedish Nuclear Fuel and Waste Management Co, 1996

7-26 Sjöblom R, Pusch R
Isostatic compaction of bentonite blocks. Present status
AR D-97-06, Swedish Nuclear Fuel and Waste Management Co, 1997

7-27 Johanneson L-E, Börgesson L, Sandén T
Compaction of bentonite blocks. Development of technique for industrial production of blocks which are manageable by man
SKB TR 95-19, Swedish Nuclear Fuel and Waste Management Co, 1995

7-28 Svemar C, Johannesson L-E, Börgesson L, Sandén T
Pre-compaction of bentonite blocks
In: Proc. of the 1996 Int. Conf. on Deep Geological Disposal of Radioactive Waste, September 16–19, 1996, Winnepeg, Manitoba, Canada, 1996

7-29 Pusch R
Consequences of using crushed crystalline rock as ballast in KBS-3 tunnels instead of rounded quartz particles
SKB TR 95-14, Swedish Nuclear Fuel and Waste Management Co, 1995

7-30 Hökmark H, Pusch R, Börgesson L, Ramqvist G
Final Report of the Borehole, Shaft, and Tunnel Sealing Test – Volume II: Shaft plugging
Stripa Project TR 87-02, Swedish Nuclear Fuel and Waste Management Co, 1987

7-31 Hökmark H, Pusch R, Börgesson L, Ramqvist G
Final Report of the Borehole, Shaft, and Tunnel Sealing Test – Volume III: Tunnel plugging
Stripa Project TR 87-03, Swedish Nuclear Fuel and Waste Management Co, 1987

7-32 Hökmark H
Plug design – Numerical Study of Rock Mechanical Conditions
PR 44-94-024, Swedish Nuclear Fuel and Waste Management Co, 1994

7-33 Hökmark H
Numerical tunnel plug study
PR D-96-007, Swedish Nuclear Fuel and Waste Management Co, 1996

7-34 Hökmark H
Design av temporär plugg i Zedex-ort
PR D-97-07, Swedish Nuclear Fuel and Waste Management Co, 1997

7-35 Pusch R, Börgesson L, Ramqvist G
Final report of the borehole, shaft, and tunnel sealing test
– Volume I: Borehole plugging
Stripa Project TR 87-01, Swedish Nuclear Fuel and Waste
Management Co, 1987

7-36 Svemar C
Alternative Retrieval Methods Considered by SKB
In: Proc. of the 4th Int. Workshop on Design and Construction
of Final Repositories, October 6–8, Lucerne, Switzerland, Nagra

7-37 Andersson C-G
Provtillverkning av kopparkapslar med gjutna insatser
under 1996 och 1997
R-98-09, Swedish Nuclear Fuel and Waste Management Co, 1998

7-38 Eriksson J
Provtillverkning av kopparkapslar för slutförvaring av använt kärnbränsle
Inkapsling PR 95-12
Swedish Nuclear Fuel and Waste Management Co, 1995

7-39 Gunnarsson D, Johannesson L-E, Sandén T, Börgesson L
Field test of tunnel backfilling
PR HRL-96-28, Swedish Nuclear Fuel and Waste Management Co, 1996

Chapter 8

8-1 SKI
SITE-94, Deep Repository Performance Assessment Project
SKI Report 96:35, Swedish Nuclear Power Inspectorate, 1996

8-2 SKI
Project-90
SKI Report 91:23, Swedish Nuclear Power Inspectorate, 1991

8-3 SKB
SKB 91. Final disposal of spent nuclear fuel
Importance of the bedrock for safety
SKB TR 92-20, Swedish Nuclear Fuel and Waste Management Co, 1992

8-4 SKBF/KBS
Final storage of spent nuclear fuel – KBS-3. Parts I–IV
SKBF/KBS, 1983

8-5 SKB
Detailed programme for research and development 1999–2004
Background report to RD&D-Programme 98
Swedish Nuclear Fuel and Waste Management Co, 1998

8-6 SKI
SKI's evaluation of SKB's RD&D-Programme 95. Review report
SKI Report 96:57, Swedish Nuclear Power Inspectorate, 1996

Chapter 9

9-1 SKB
Detailed programme for research and development 1999–2004
Background report to RD&D-Programme 98
Swedish Nuclear Fuel and Waste Management Co, 1998

Chapter 10

10-1 SKB
Technology and costs for decommissioning of Swedish nuclear power plants
SKB TR 94-20, Swedish Nuclear Fuel and Waste Management Co, 1994

10-2 IAEA
Methodology and technology of decommissioning nuclear facilities
IAEA Technical Report Series. No 267, Vienna, 1986

10-3 OECD/NEA
The NEA co-operative programme on decommissioning
The first ten years
OECD/NEA, Paris, 1995

10-4 Simon R, Huber B
R&D for Decommissioning in the European Communities – Present activities and future tasks
Presented at OECD/NEA/IAEA International Seminar on Decommissioning Policies, Paris, 2–4 October, 1991

10-5 Simon R
The European Union's R&D in the Field of Decommissioning
In proc. of the International Conference on Decommissioning of Nuclear Installations
Luxembourg, 26–30 September, 1994

Table of contents of environmental impact statement for siting of deep repository

The radioactive waste from nuclear power is being stored or disposed of today in existing facilities, and will continue to be for several decades to come. Eventually, however, the main line in SKB's planning calls for construction of an encapsulation plant and a deep repository for spent nuclear fuel and other long-lived waste. Since these plants are linked to each other, they should be regarded as a single system. Even though this appendix primarily deals with what should be included in an environmental impact statement (EIS) for a deep repository, most of it is also applicable to an encapsulation plant.

In the case of the deep repository, the application for a permit to undertake a detailed characterization (siting application for a deep repository on a site) must be accompanied by an EIS. The EIS, which is the result of an EIA (environmental impact assessment) process, should deal with both the facility itself and the system for final disposal of which it is a part. Furthermore, it should give an account of alternative disposal methods and alternative sites, as well as the zero alternative. The zero alternative describes what happens if the project is not realized, which in this case may mean extended (up to hundreds of years) supervised storage of the spent fuel in CLAB (Central interim storage facility for spent nuclear fuel) at the Oskarshamn Nuclear Power Plant.

This appendix outlines the possible contents of an EIS to be appended to the application for a permit for detailed characterization. The purpose is to utilize the broad review and commentary process which RD&D-Programme 98 will undergo to obtain early views on what should be included in the EIS. SKI has announced that they intend to prescribe what should be included. Another purpose is to use this appendix to initiate discussions in the EIA consultation groups that work at the national level chaired by the national coordinator, at the regional level chaired by the relevant county administrative board, and at the local level within the concerned municipalities.

The table of contents presented here should therefore not be regarded as something finalized by SKB, but rather as a first draft to initiate a broad discussion of the future EIS document. In general, the process leading up to an EIS should be characterized by the following:

Transparency: It is assumed that the EIA process takes place in collaboration between the parties. The public is included as a source of knowledge. To lead to correct decisions, the facts must be presented clearly and correctly.

Systematics: The EIA process should be carried out stepwise to facilitate focusing on those matters that are essential at different stages of the work. To avoid unnecessary questions and supplemen tary work, policy decisions and important information should be documented in a clear and comprehensible fashion.

Relevance: The EIA process should be concentrated on factors that are conclusive for an overall assessment of a deep repository on the selected site and effects of proposed safety measures. The finished EIS should contain conclusions that permit a judge ment to be made as to whether good prospects exist for building a repository on the selected site.

In order to provide ample time for important questions to be dealt with, the EIA work will be carried out in three steps: **delimitation** of questions, **penetration/analysis** and **reporting**. Depending on how far certain questions have come at a given point in time, these steps will partially overlap.

The way in which the environment can be affected by a given activity can be described in terms of impact, effects and consequences. We can take noise to illustrate this. By "impact" is meant with this terminology that the activity gives rise to noise, while the term "effect" also includes the sound level of the noise and how the noise varies throughout the day. By "consequence" is meant, for example, noise injuries, or the fact that certain bird species disappear as a result of the noisy activity. The feasibility studies inventory and describe what impact a deep repository can have on the environment. In the next phase, site investigations, when specific sites have been designated, effects and consequences will also be analyzed.

Proposed contents of an EIS

Since the proposal is intended to provide a framework for the scope and thrust of an EIS, the explanations under each heading have deliberately been kept brief. The following main sections are included in this proposal:

- Introduction.
- Execution of EIA.
- Account of alternatives.
- Technical description.
- Site description.
- Environmental impact and environmental effects.
- Description of consequences.
- Institutional controls.
- Appendices and principal background reports.

The deep repository is a controversial facility. Many questions that are discussed in the feasibility studies and in other contexts do not concern the environmental impact, but rather the psychosocial and societal impact of a deep repository establishment. We believe that these questions are important and should be included in the environmental impact statement.

Following is a description of the proposed contents of each main heading.

Introduction

The section describes the Swedish system for management of nuclear waste and radioactive waste, as well as SKB's mission to frame proposals for how and where ultimate disposal of the long-lived waste from the nuclear power plants is to take place. Among other things, an account will be given of the following:

- The Swedish system for management and disposal of nuclear and radioactive waste.
- Planned facilities: the encapsulation plant and the deep repository.
- The context of the EIS.
- Applicable legislation.
- Relevant government regulations.
- Advice and instructions regarding the scope of an EIS.
- Reading instructions.

Execution of EIA

This section describes how the EIA process has been carried out, how viewpoints have been dealt with and what delimitations have been made. Further, the underlying material that has been used is described. The following topics are dealt with:

- Actors in the EIA process.
- Organization, information and consultation procedures in the EIA.
- Different steps in the EIA.
- Minutes from consultation meetings.
- How the EIA has influenced decisions concerning the project and the EIS.
- Delimitations of the work with the EIA and the EIS.
- Planning documents that have been produced during the course of the process.
- Other applicable studies of technical, societal and economic questions.
- Limitations and uncertainties in the underlying data and the methods that have been used.
- Review and quality control of the investigation work.

Account of alternatives

The disposal method and the site which SKB considers to be the most suitable for minimizing the long-term environmental consequences are described under this heading. Further, the consequences if the facility is not realized at all (the zero alternative), as well as the advantages and disadvantages of other methods and sites, are described. The following topics are included:

- Selected (applied-for) alternative (choice of method).
- Recommended technical design and siting.
- Alternative designs/layouts within the framework of the chosen method.
- Alternative sitings.
- Zero alternative.
- Alternative methods.

Technical description

The section describes all activities involved in siting, construction, operation and closure/decommissioning of the deep repository. The description will be adapted to the sites investigated. The following topics are included:

- Description of activities during the different phases of the project (also includes planned quantity of deposited waste).
- Timetable.
- Description of buildings and facilities.
- Description of construction and civil engineering works.
- Use of vehicles and machines, etc.
- Activities and number of employees during different phases.
- Description of underground facilities.
- Description of rock excavation works, handling of rock spoils.
- Need for raw materials and natural resources.
- Waste arisings.

- Description of radiological protection measures.
- Utilities (roads, water, sewerage, electricity, telephones and heat).
- Transport needs during different phases and waste shipments.
- Secondary effects (need for other facilities, housing, etc.).
- Decommissioning and post-closure site restoration/remediation.

Site description

The section gives an account of conditions on the site recommended by SKB and the other site where site investigations are carried out. The following topics are covered for each site:

- Land use and plan situation.
- Existing infrastructure.
- Natural and cultural values.
- Other values for residents, for outdoor recreation and for biological diversity.
- Geoscientific conditions, both near-surface and at the planned repository depth.

There will be a large body of geoscientific material from the site investigations and safety assessments. To make the EIS manageable and readable, the main text will be concentrated on the most important results.

Environmental impact and environmental effects

The section describes the environmental impact and the environmental effects which a deep repository has on the chosen site both during construction and operation of the repository and in the long time perspective. Particular emphasis is placed on reporting uncertainties. A corresponding description is also provided for the other site on which site investigations have been carried out, as well as for the zero alternative. The account is provided for the different phases of the project: detailed characterization, repository construction, deposition phase, possible interrupted deposition and retrieval of waste, and post-closure period. The following topics are included:

- Emissions of radioactive substances to air and water,
  during transport,
  during handling at the deep repository,
  after deposition.

- Direct radiation from radioactive substances,
  during transport,
  during handling at the deep repository,
  after deposition.

- Emissions of other substances to air and water,
  during transport,
  during civil engineering works,
  during handling at the deep repository,
  after deposition.

- In utilization of land, facilities,
  area that is blocked (on the surface and at depth),
  changes and restriction of land use,
  changes in groundwater conditions.

- Changes in landscape,
  heaps of shot rock,
  buildings.

- Other impacts such as noise, vibration, lights,
  during transport,
  during civil engineering works,
  during deposition.
- Accidents

Description of consequences

The consequences which planned facilities have on the environment, health and management of natural resources are described so that an overall assessment can be made. This account can be structured in several ways. It is proposed that the account be divided up on the basis of what can be affected as follows:

Environment

Refers primarily to consequences in the natural and cultural environment, for example particularly valuable areas, individual plant and animal species, ecosystems.

Health and safety

Refers to consequences for personnel, residents and visitors from both radiological impacts and from other sources. Psychosocial and societal consequences are also described under this heading.

Resource management

Refers to consequences for natural resources such as agricultural and forest land, fishing, reindeer herding, groundwater, mineral resources, gravel and stone.

What will be discussed in this section will depend on what environmental effects are judged to be important to quantify. The EIA consultation groups will play an important role in making this judgement. The description of consequences will also include societal and psychosocial aspects, even though these aspects are largely a question of attitudes and values and are therefore difficult to quantify.

What will be described will therefore have to emerge during the EIA process. Examples of consequences that will be described are:

- Consequences of ionizing radiation in connection with normal operation.
- Consequences of ionizing radiation in connection with accidents during the operating period.
- Consequences of ionizing radiation in connection with interrupted deposition and retrieval.
- Post-closure repository safety and consequences of various scenarios.
- Consequences of delayed closure.
- Risk and consequence of future human intrusion.
- Consequences of changed land use, e.g. blocking of natural resources.
- Consequences of emissions to air and water from motor vehicle traffic, blasting gases and other activities.
- Other consequences of operation, e.g. noise, vibration or lights.
- Consequences of groundwater drawdown, rock heaps and altered landscape.
- Consequences of accidents, fire, etc.

- Consequences for natural resource management.
- Consequences for other economic activities, such as the travel industry, fishing and agriculture.
- Societal consequences of increased employment and settlement in the region.
- Consequences for real estate prices.
- Psychosocial consequences of anxiety or well-being.

The preventive measures that can be adopted to minimize risks and mitigate consequences for health and environment are described for each point.

Institutional controls

The section describes control programmes and follow-up routines:

- Need for long-term monitoring of repository performance.
- Control to ensure that fissionable materials are not removed (safeguards).
- Restrictions, for example on earthmoving works and drilling of wells.
- Possible environmental impact of a control programme.

Appendices and principal background reports

The EIS will make reference to appendices and background reports. Some of the most important of these will be:

- Applicable legislation and regulations governing permissible doses, effects, limit values, etc.
- Technical description of the repository.
- System analysis.
- Description of the EIA process, consultations, delimitations, how the process has influenced decisions relating to the project and contents of the EIS.
- Account of alternative methods and reasons for chosen alternative.
- Account of zero alternative.
- Summary of general siting studies.
- Summary of feasibility studies.
- Integrated account of siting data for the selection of at least two sites.
- Evaluation factors and criteria for site investigations.
- Summary of site investigations for a given site.
- Safety assessment of a deep repository on a given site.
- Radiological risk and accident analysis for encapsulation, transport and deposition.
- Consequences of radioactive releases at a given site and for the zero alternative.
- Account of non-radiological environmental consequences for a given site and for the zero alternative.
- Summary of planned detailed characterization.