SKB

TECHNICAL REPORT 85-20

SKB ANNUAL REPORT 1985

Including Summaries of Technology Reports Issued during 1985

Stockholm May 1986

SVENSK KÄRNBRÄNSLEHANTERING AB
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PREFACE

During 1985 the last two reactors in the Swedish nuclear power program were taken into operation. Thus Sweden now has all its twelve nuclear reactors in operation. During 1985 42% of the total electric power was generated at nuclear power plants.

Also during 1985 operation started of the facility for interim storage of spent fuel (CLAB). CLAB constitutes a fundamental strategic function in the Swedish spent fuel management system. It will ensure the uninterrupted nuclear power production and it will provide ample time for the R&D-work, the site selection and the system's design and optimization needed to achieve a suitable and safe system for spent fuel management including final disposal. That will also mean a freedom of choice on the option to be finally implemented.

The Annual Report 1985 is extended in comparison to previous annual reports in this series. In addition to the reporting on R&D-work performed during the year a general overview of all main activities of SKB during 1985 has been included as part I of this report.

Sten Bjurström
President

ABSTRACT

This is the annual report on the activities of the Swedish Nuclear Fuel and Waste Management Co, SKB. It contains in part I an overview of SKB activities in different fields. Part II gives a description of the research and development work on nuclear waste disposal performed during 1985.

Lectures and publications during 1985 as well as reports issued in the SKB technical report series are listed in part III.

Part IV contains the summaries of all technical reports issued during 1985.

SKB is the owner of CLAB, the Central Facility for Intermediate Storage of Spent Nuclear Fuel, located at Oskarshamn. CLAB was taken into operation in 1985 and at the end of the year about 100 tonnes of spent fuel were stored at CLAB. Transportation from the nuclear sites to CLAB is made by a special ship, M/S SIGYN.

At Forsmark a final repository for low- and medium level waste is being built. The repository is situated in crystalline rock under the Baltic Sea. All tunnels and rock caverns in the first phase have been excavated. After the finalisation of concrete structures and installation of handling machines and auxiliary systems the repository will be commissioned in the beginning of 1988.

SKB is in charge of a comprehensive research and development program on geological disposal of nuclear waste. The budget for 1985 was about 70 MSEK. Some of the main areas for research are

- Characterization and leaching of spent nuclear fuel
- Properties of bentonite for buffer, backfilling and sealing
- Groundwater chemistry and nuclide migration
- Methods and instruments for in situ characterization of crystalline bedrock
- Natural ageing of recipients in the biosphere
- Model development and safety assessment.

Geological site-investigations are a substantial part of the program. Further, SKB is the managing participant of the international Stripa-project under OECD/NEA.

Cost calculations for the total nuclear waste management system, including decommissioning of all reactors, are updated annually. The total cost is estimated to SEK 46 billion which is approximately 10% of the value of the electricity being produced.

Consulting services from SKB and associated expert groups are now available on a commercial basis. They are coordinated and marketed through SwedPower, which has the same main owners as SKB.

A department of public affairs has been established within SKB during 1985.

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1 GENERAL BACKGROUND

1.1 THE SWEDISH NUCLEAR POWER PROGRAM

Swedens nuclear power program consists of 12 nuclear reactors located at four different sites and with a combined capacity of 9 650 MW electric power. In 1985 the last two reactors of this program, Forsmark 3 and Oskarshamn 3, reached full power and were taken into commercial operation. Main data and location of the 12 units are shown in Figure 1-1. The nuclear power plants generated 42% of the total Swedish electric power produced in 1985.

Swedish reactors

Reactor		Power MW_e	Commercial operation	Energy Availability in 1985 %
Oskarshamn 1	BWR	440	1972	73
Oskarshamn 2	BWR	595	1974	88
Oskarshamn 3	BWR	1050	1985	(92) ☆
Barsebäck 1	BWR	595	1975	88
Barsebäck 2	BWR	595	1977	97
Ringhals 1	BWR	750	1976	85
Ringhals 2	PWR	800	1975	74
Ringhals 3	PWR	915	1981	84
Ringhals 4	PWR	915	1983	87
Forsmark 1	BWR	972	1980	86
Forsmark 2	BWR	972	1981	88
Forsmark 3	BWR	1050	1985	(96) ☆

☆ from start of commercial operation

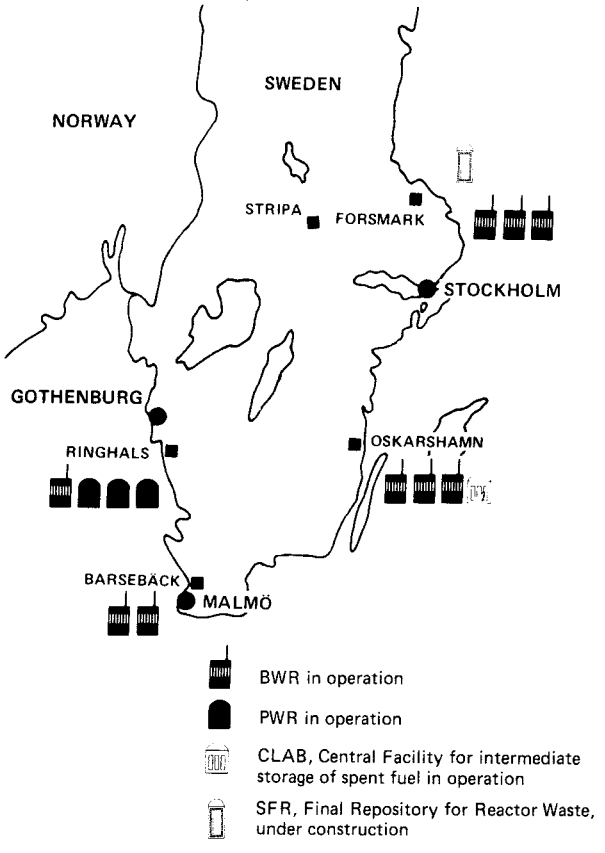


Figure 1-1. The Swedish nuclear power program.

1.2 LEGAL FRAMEWORK AND ORGANIZATION

The nuclear power plants are owned by the following four companies

- Statens Vattenfallsverk (Swedish State Power Board; Vattenfall) is the largest electricity producer in Sweden and owns the Ringhals plant.
- Sydsvenska Värmekraft AB (subsidiary of Sydkraft AB) is the owner of the Barsebäck plant.
- OKG AB is the owner of the Oskarshamn plant. Sydkraft is the major shareholder of OKG.
- Forsmark Kraftgrupp AB (FKA) owns the Forsmark plant. Vattenfall has 74.5% of the shares in FKA.

The Swedish Nuclear Fuel and Waste Management Company, SKB (SKB = Svensk Kärnbränslehantering AB) has been formed by these four power utilities. SKB shall develop, plan, construct and operate facilities and systems for the management and disposal of spent nuclear fuel and radioactive wastes from the Swedish nuclear power plants.

SKB is also in charge of the comprehensive research program in the waste field which the utilities are responsible for according to the law. Finally SKB handles matters pertaining to prospecting, enrichment and reprocessing services as well as stockpiling of uranium for the Swedish nuclear power industry and provides assistance at the request of its owners in uranium procurement.

The total staff of SKB is about 45 persons. The organization is presented in some detail in Appendix 1. The bulk of the work is made by contractors.

The assignment dominating the activities of SKB is the nuclear waste management. The obligations are regulated by various laws and supervised by several authorities. Figure 1-2 gives an overview of the most important laws and authorities involved and the relation to SKB activities.

There are three important laws which regulate the nuclear activities:

- The Act on Nuclear Activities
- The Act on the Financing of Future Expenses for the Disposal of Spent Fuel etc.
- The Radiation Protection Act.

The Act on Nuclear Activities /1-1/ puts the primary responsibility for the safety on the owner of a nuclear installation. The owner is thus responsible for safety at design, construction and operation of nuclear facilities, for the handling and final disposal of nuclear wastes and for the dismantling and decommissioning of the facility. The responsibility also includes the necessary research and development in the waste management field. According to the act a research program must be submitted to the authorities every three years starting 1986.

The authorities for supervision of the safety provisions in the Act on Nuclear Activities are the Swedish Nuclear Power Inspectorate (SKI), and the National Institute for Radiation Protection (SSI). The research program is supervised by the National Board for Spent Nuclear Fuel (SKN).

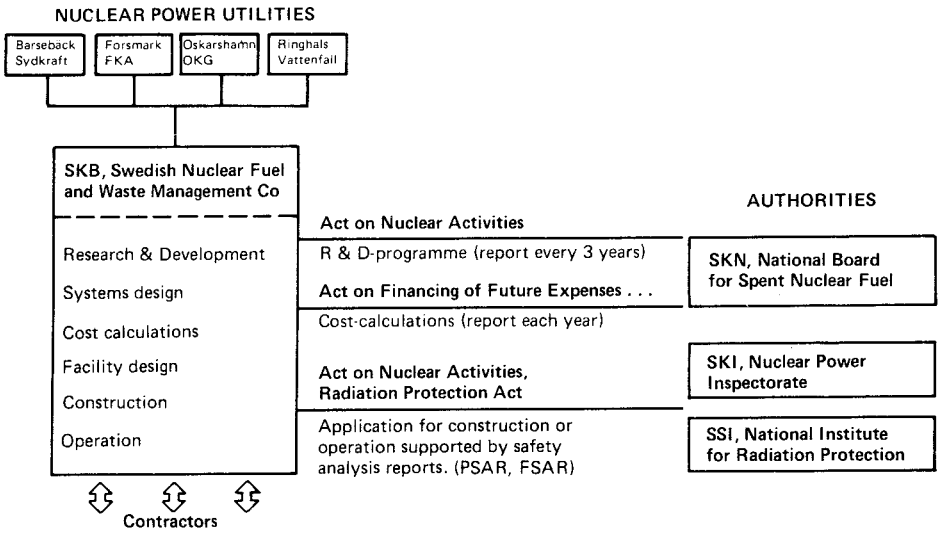


Figure 1-2. Legal framework for activities of SKB.

The latter authority is also the competent body for supervising the adherence to the Act on Financing of Future Expenses for Spent Fuel. According to this law the waste management activities including future decommissioning of all reactors are financed from a fund built up from fees on the nuclear power production.

The fee is revised annually by SKN, which proposes the fee for the next year to the government. The fee has been set to 0.019 SEK per kWh for the years 1984-1986.

The radiation protection act contains basic rules for protection against ionizing radiation for

- those who work at nuclear installations and other facilities with potential radiation hazards
- the general public who lives or stays outside such installations or facilities.

The competent authority in these matters is the Swedish National Institute for Radiation Protection (SSI).

SKB is thus the organization that has the lead operative role in the Swedish waste management program both with respect to planning, construction and operation of facilities and systems and with respect to research and development. The role has its roots in the legislation briefly described above.

In addition the three competent authorities are performing the research needed for their own respective obligations. SKN is also supporting research intended to supplement the SKB-program. In order to coordinate the research programs carried out by the authorities a special "Consultative Committee for Nuclear Waste Management" was founded in 1985. The council shall report to the government annually on the state of the art in the nuclear waste field.

1.3 THE SWEDISH NUCLEAR WASTE MANAGEMENT SYSTEM

A complete system has been planned for the management of all radioactive residues from the 12 nuclear reactors and from research facilities. The system is based on the projected generation of waste up to the year 2010.

Residues generated by the operation of the reactors are spent nuclear fuel and different kinds of low- and medium level wastes. Furthermore, in the future decommissioning waste will be generated when old reactors are dismantled.

The types and total quantities of various nuclear waste categories currently estimated to be generated are given in Table 1-1.

The basic strategy for the management of the various waste categories is that short-lived wastes should be deposited as soon as feasible, whereas for spent fuel and other long-lived wastes an interim storage period of 30-40 years are foreseen prior to disposal.

The main features of the planned system for nuclear waste management in Sweden are shown in Figure 1-3.

For low- and medium level reactor waste a central final repository, SFR, is under construction and is planned to be operative in 1988. SFR may later on be extended to accomodate also waste from the decommissioning of the nuclear reactors.

For spent fuel a central interim storage facility, CLAB, was taken into operation in July 1985. This facility has a capacity of 3 000 tonnes of spent fuel, with a possibility to extend it to cover the total Swedish needs.

After approx. 40 years of interim storage in CLAB, the fuel will be encapsulated in a corrosion resistant container and deposited at about 500 meters depth in the Swedish bedrock. The encapsulation and disposal will only start operation around 2020, and the site has thus not been chosen yet.

A minor amount of spent fuel is contracted for reprocessing. See further 7.2. The wastes from reprocessing, i.e. vitrified high-level waste and transuranic low- and medium level waste may be sent back to Sweden for storage and disposal. The management system thus also includes an interim storage facility for these wastes.

For the transport of spent fuel and other kinds of radioactive wastes a sea transport system is used.

Table 1-1. Waste categories.

WASTE CATEGORY	ORIGIN	WASTE FORM	PROPERTIES	QUANTITY
1a Spent fuel	Operation of nuclear reactors	Fuel rods encapsulated in copper canisters	High heat flux and radiation at first. Contains long-lived nuclides	5 150 canisters (7 100 tu)
1b High-level waste	Residual products from reprocessing	Vitrified waste encapsulated in lead-titanium canisters	High heat flux and radiation at first. Contains long-lived nuclides	550 canisters (550 tu)
2 Transuranic-bearing waste	Waste from the reprocessing process	Solidified in concrete or bitumen	Low- to medium-level. Contains long-lived nuclides	4 300 m^3
3 Core components and internals	Scrap metal inside reactor tanks	Untreated or cast in concrete	Low- to medium-level. Contains certain long-lived nuclides	15 000 m^3
4 Reactor waste	Operating waste from nuclear power plants etc.	Solidified in concrete or bitumen. Compacted waste	Low- to medium-level. Limited life time	100 000 m^3
5 Decommissioning waste	From dismantling of nuclear facilities	Untreated for the most part	Low- to medium-level. Limited life time	115 000 m^3

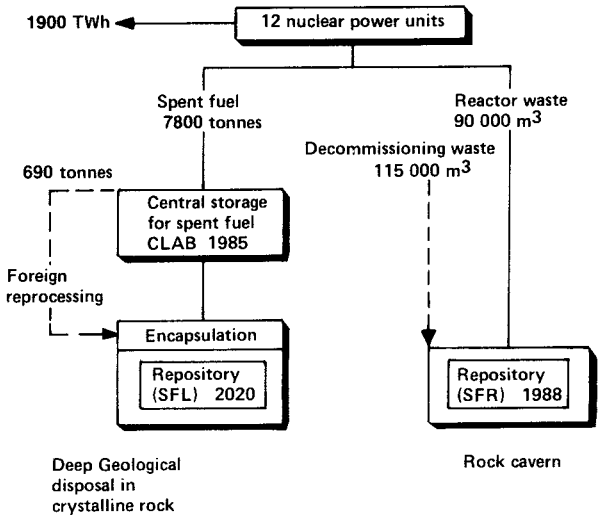


Figure 1-3. Main system for management of radioactive waste in Sweden.

2 NUCLEAR FUEL SUPPLY

In the front end of the nuclear fuel cycle SKB handles matters pertaining to prospecting and enrichment as well as stockpiling of uranium for the Swedish nuclear power industry. SKB also provides assistance at the request of its owner utilities in uranium procurement.

2.1 NATURAL URANIUM

2.1.1 The Swedish Situation

The Swedish nuclear power program has an annual natural uranium demand of about 1 300 metric tonne. This demand could be higher or lower depending on a number of factors, which means that the planning of supply must be flexible.

The demand for the period 1985 up to 1990 is 7 800 tonne. At the end of 1985, the Swedish utilities had contracts for supply of 6 800 tonnes during the same period. Most of the supply is based on long-term contracts. As the prices on the spot market were low in 1985, some spot quantities were purchased.

Natural uranium is delivered to Sweden mainly from Canada and Australia, but also from Niger, Gabon and USA. Canada is responsible for more than 50% of future deliveries under present contracts.

At present, the contracted supply for the 1990 is only 1 100 tonnes. However, during 1985 the utilities started discussions with mining companies with the objective to increase long term contracts for this period.

Exploration

Uranium occurs in relatively high concentrations in certain parts of the Swedish Precambrian rock. SKB has therefore been conducting exploration at a number of places in northern Sweden. Mineralizations containing at least 6 000 metric tonnes of uranium have been found with concentrations higher than 1 000 g uranium per ton ore. These ores constitute important reserves for the future.

During 1985, exploration was concentrated to mineralizations in the community of Åsele.

As uranium supply is abundant and the market price is low, SKB stopped exploration at the end of 1985.

Ranstad

Sweden has considerable uranium resources. Most of the proven reserves consist of relatively low-grade shale deposits near Ranstad with about 300 g uranium per ton of shale. These deposits are not exploitable at the present low price of imported uranium.

2.1.2 The International Situation

Demand and Supply

The consumption of uranium in the world (except centrally planned economies) is estimated to 39 000 tonnes, while the production is estimated to 37 000 tonnes. This does not present a problem, as there are about 130 000 tonnes in stocks.

Market-prices

Figure 2-1 shows the price situation for uranium during the last years. Spot prices were low in 1985.

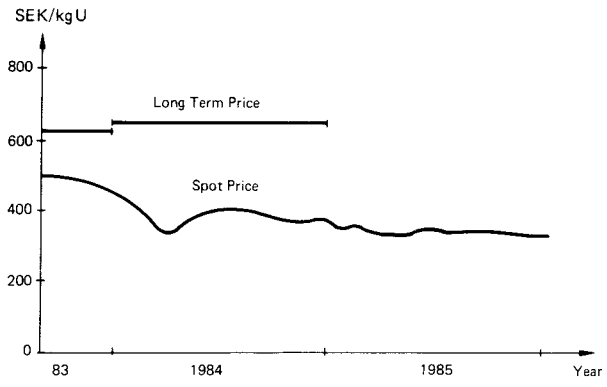
The average price for long term deliveries in 1984 to the European Community was considerably higher than spot prices for the same delivery year.

2.2 CONVERSION

Conversion is a chemical process for production of uranium hexafluoride from uranium concentrates.

The world conversion capacity is around 52 000 tonnes of uranium per year while the demand is about 37 000 per year.

The Swedish utilities utilize conversion services from Canada, USA, United Kingdom and France.



Long term price = Average price for long term deliveries to the European Community

Spot price = Average spot price each month published by the German Company NUKEM

Figure 2-1. Long term and spot prices for uranium.

2.3 ENRICHMENT

2.3.1 Supply to Sweden

Up to 1983, enrichment deliveries to the Swedish utilities were dominated by DOE in the USA and Techsnabexport in the USSR.

The European enrichment industry became price competitive in the beginning of the 1980-ies. During the period 1983-1985 Swedish utilities signed contracts for deliveries from Western Europe, which started already 1984.

For the period 1986-1990, most of the deliveries to Sweden will come from EURODIF with an enrichment plant in France and from URENCO with enrichment plants in the Netherlands, the United Kingdom and in Germany. Deliveries from the USSR will continue as earlier, while deliveries from the US will continue on a reduced scale. This situation gives a reliable supply with deliveries from four different companies.

2.3.2 Market

The total enrichment capacity now available, around 34 million SWUs per year is higher than the demand for separative work, which can be estimated to 22 million SWUs in 1985.

The present capacity will probably be sufficient up to the mid-1990.

2.4 FABRICATION OF FUEL ASSEMBLIES

Fabrication of fuel assemblies is made in Sweden at the ASEA-ATOM plant in Västerås.

The Swedish utilities are purchasing fuel fabrication services with the objective of lowest cost. This procedure has led to many orders from ASEA-ATOM, but also orders from the US, Germany and France.

Fuel fabrication at ASEA-ATOM 1985 was around 145 tonne for Boiling Water Reactors and 80 tonne for Pressurized Water Reactors. Of this production, about 28 tonne were exported to Finland.

A normal fuel assembly for a Boiling Water Reactor has 63 (=8 x 8 - 1) fuel rods.

ASEA-ATOM has developed a new fuel assembly, called SVEA, where the fuel rods are divided in four groups with 4 x 4 fuel rods in each. These parts are separated by a water cross made of zirkaloy.

The new SVEA fuel element gives a more even burn-up, and thus a better possibility to utilize the energy from the inner fuel rods. Actually SVEA will produce 8-10% more energy than a conventional fuel element from a given amount of natural uranium and enrichment.

The introduction of SVEA started five years ago with some fuel assemblies for demonstration. In 1985, about 270 SVEA fuel elements were loaded in reactors and ASEA-ATOM had orders for about 25 reloads to Swedish and Finnish reactors as well as 6 reloads in US reactors via a licensing agreement with Westinghouse and 6 reloads for a Swiss reactor.

2.5 NUCLEAR FUEL STOCKPILE

Swedish Nuclear Fuel and Waste Management Co. is on account of the utilities responsible for stockpiling enriched uranium and zirkaloy corresponding to an electricity production of 35 TWh. This amount has been decided by the Swedish parliament.

Uranium in the abovementioned stockpile, in fuel under fabrication and at the nuclear power stations is sufficient for about two years of operation of all 12 units.

2.6 COSTS

The costs for the front end supply and services of the nuclear fuel cycle in 1985 were as shown in Table 2-1 (the production of nuclear electricity was 56 TWh in 1985):

Table 2-1. Costs for the front end of the nuclear fuel cycle.

	SEK/kWh	Million SEK in 1985
Natural uranium	0.011	620
Conversion	0.001	60
Isotope enrichment	0.016	900
Fuel fabrication	0.006	340
Strategic stockpile	0.001	60
Total front end	0.035	1 980

3 INTERMEDIATE STORAGE OF SPENT FUEL, CLAB

3.1 GENERAL

The Swedish interim spent fuel storage facility CLAB, located on the Simpevarp peninsula adjacent to the Oskarshamn nuclear power station was taken into active operation on July 11th 1985.

The facility consists of five underground storage pools for in total 3 000 tonnes of uranium. The reception, auxiliary and office buildings are located on ground level. See Figure 3-1. The facility is designed to receive at least 300 tonnes uranium per year which corresponds to about 100 transport flask handlings.

Main suppliers contracted by SKB in realizing the CLAB facility has been ASEA-ATOM (AA), Sweden, Socité Genérale pour les Techniques Nouvelles (SGN), France and a Swedish building consortium consisting of SKANSKA, Aktiebolaget Vägförbättringar (ABV) and Widmark och Platzer (WP).

The project management has been entrusted to OKG AB who is one of the SKB share holders. OKG AB is also the operator of the facility.

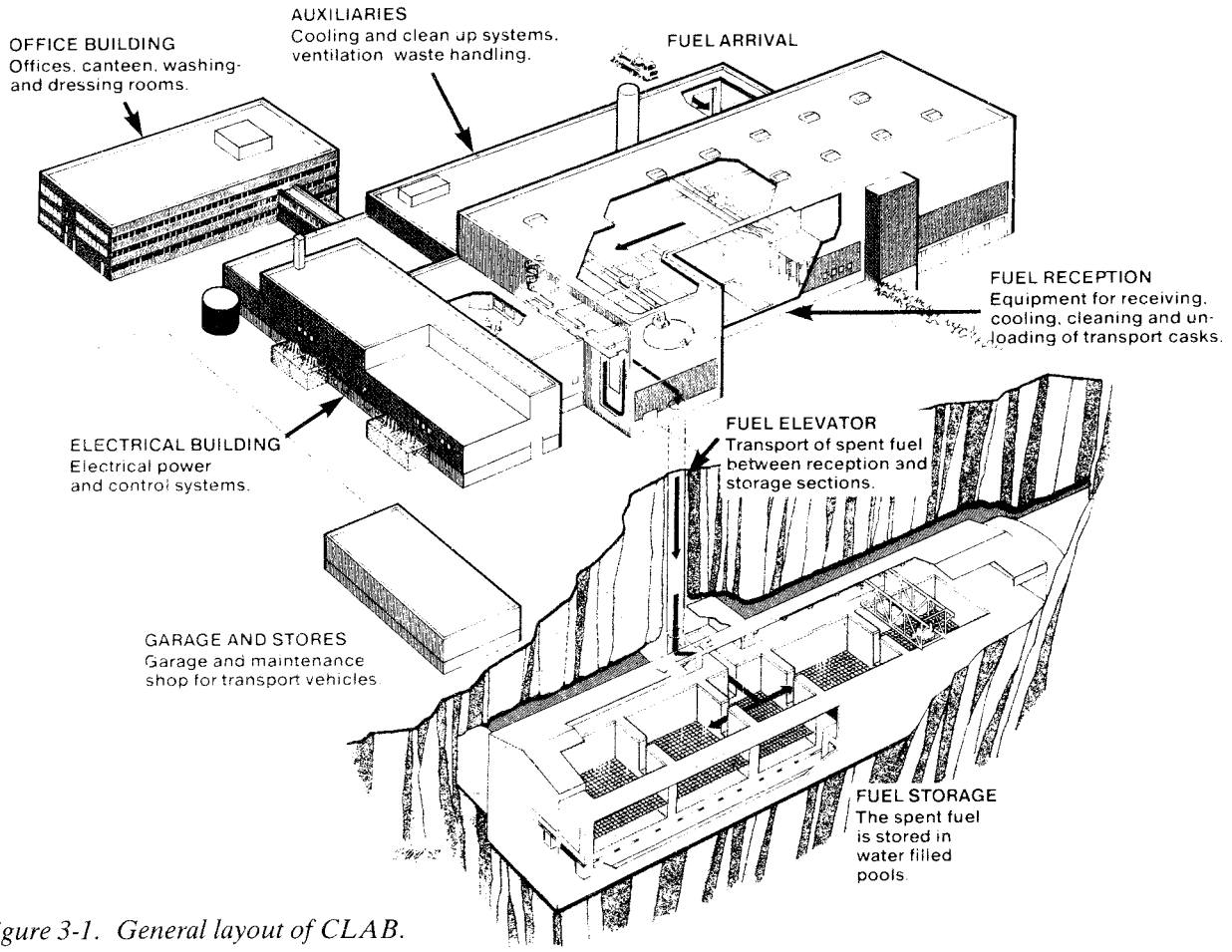


Figure 3-1. General layout of CLAB.

3.2 COMMISSIONING AND OPERATION OF CLAB

Inactive commissioning started late 1984 and all systems were tested. During spring 1985 integrated tests of the different systems were carried out and finally the facility was tested under inactive conditions using normal transport flask and dummy spent fuel.

Test reports were on a continued base submitted to the Swedish Nuclear Power Inspectorate and the National Institute for Radiation Protection for their evaluation. Finally, a summary test report was submitted to the authorities and at the same time SKB asked for approval to start-up the plant under active conditions. Approval to start active operations was obtained on June 19th. The operating permit was temporarily limited to 1985-12-31 and in due time SKB was requested to submit a report describing the experiences from the first period of active operations. The authorities specified a limited number of requirements which should be followed by special care.

In the first active test period the capacity was gradually increased to finally reach the nominal annual capacity. 90% of the planned reception of spent fuel has been carried out. In addition more flasks than planned containing reactor core components have been received.

In general the experiences from the first active test period have been favorable. Some minor disturbances have occured such as:

- 3 weeks interruption in fuel reception because of defect filter pots in the flask cooling down circuit,
- suspected defect fuel were detected in the flask cooling down system but after sipping of all the spent fuel assemblies from that particular flask it was considered as non-defect. This operation caused some minor delay in the program.

Based on the successful active test period, SKB requested at the end of November 1985, the license approval for continued active operation. The license given by the authorities is now limited to June 30th 1986. SKB is requested to submit the results from this second test period before receiving a permanent operation license. During this second period the plant will be operated at its yearly nominal capacity.

At the end of 1985 100 tonnes of spent nuclear fuel were stored at CLAB.

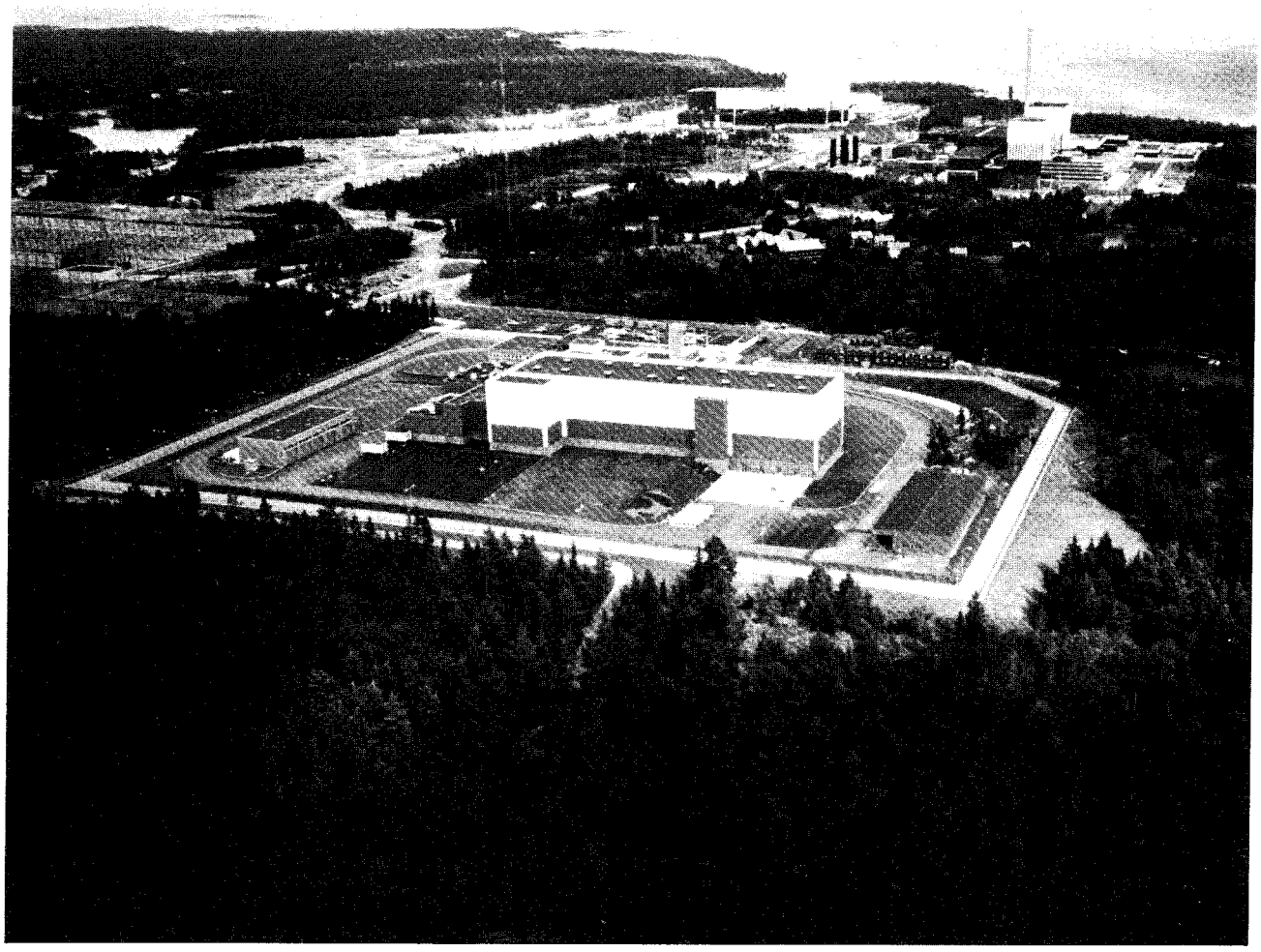


Figure 3-2. Aerial view of the CLAB facility. The Oskarshamn nuclear power plants can be seen in the background.

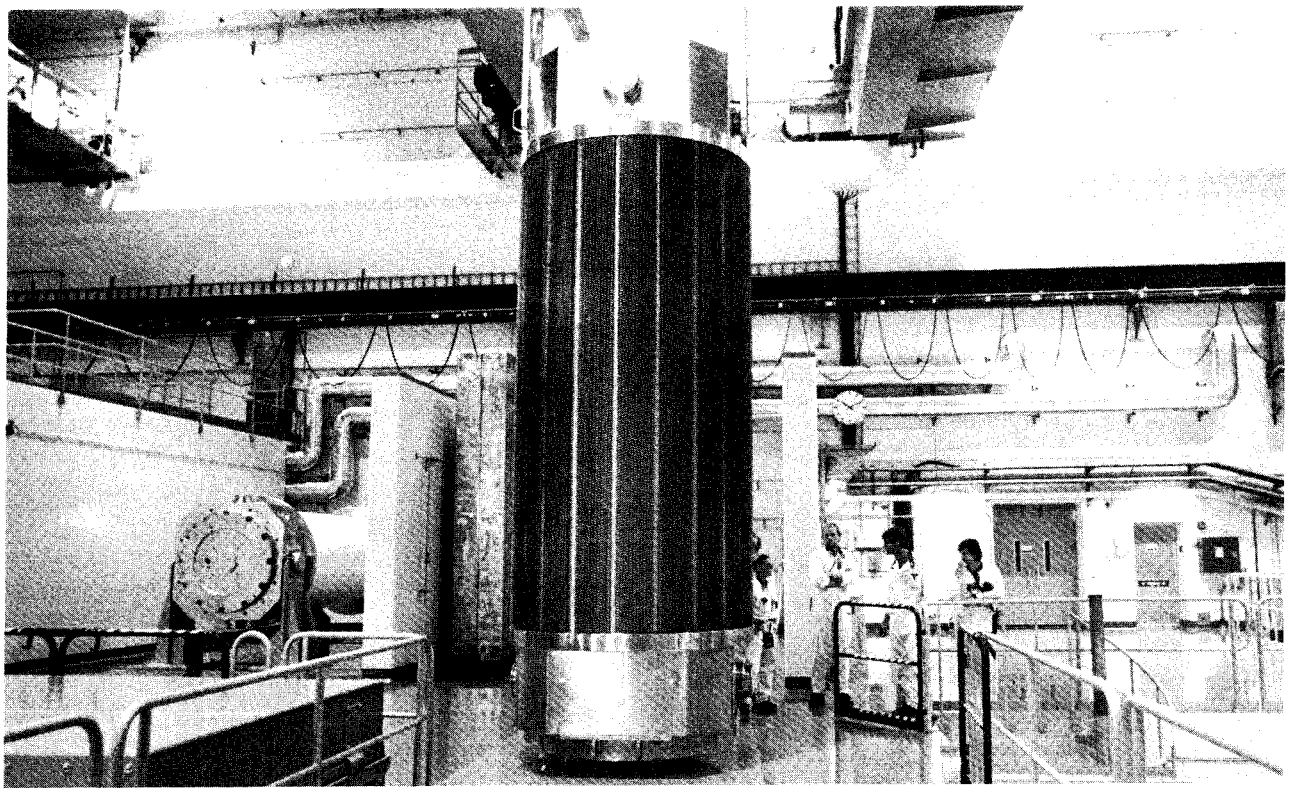


Figure 3-3. Transport flask in the fuel reception building at CLAB.

4 TRANSPORTATION SYSTEM

4.1 GENERAL

SKB has a sea transportation system for spent fuel and all kinds of radioactive materials in operation. The system consists of:

- a specially designed ro-ro/lo-lo ship,
- 10 transport flasks and its auxiliary equipment for spent fuel,
- 2 transport flasks for reactor core components,
- 3 specially designed terminal transport vehicles.

The ship and part of the system was commissioned in 1982 and has been used for transportation of spent fuel to the reprocessing plant at La Hague in France. As from July 1985 the system is mainly used for transportation of spent fuel from the reactors to the CLAB facility. From 1988 it will also be used for transportation of reactor wastes to the final repository for reactor waste, SFR. Special transport containers are being designed for the transport of reactor waste. Approximately 40-50 containers will be manufactured during the period 1986 - 1988 for that purpose. Each ship voyage can carry ten such containers with a total pay load of approximately 1 200 tonnes.

4.2 OPERATION EXPERIENCE

Nine sea-voyages each with 4-5 transport flasks have been carried out during 1985 to the CLAB facility. The operation of the transport system has been successful, and no disturbances have occured. The crew on board the ship M/S Sigyn has so far not received any additional radiation doses compared to the normal background level. The time schedule has been kept during all the voyages.

The decay heat in the transport flasks has so far not exceeded 15 kW compared to permitted 45 kW, this resulting in a surface temperature of 36°C compared to permitted 83°C. The spent fuel transported so far always had a cooling time after discharge from the reactor of more than 2 years. Thus the surface dose rate has been low; 0,15 mSv/h compared to 2 mSv/h allowed according to the IAEA-recommendations.

During 1986 some 15-20 voyages are planned for transport of spent fuel to the CLAB facility.

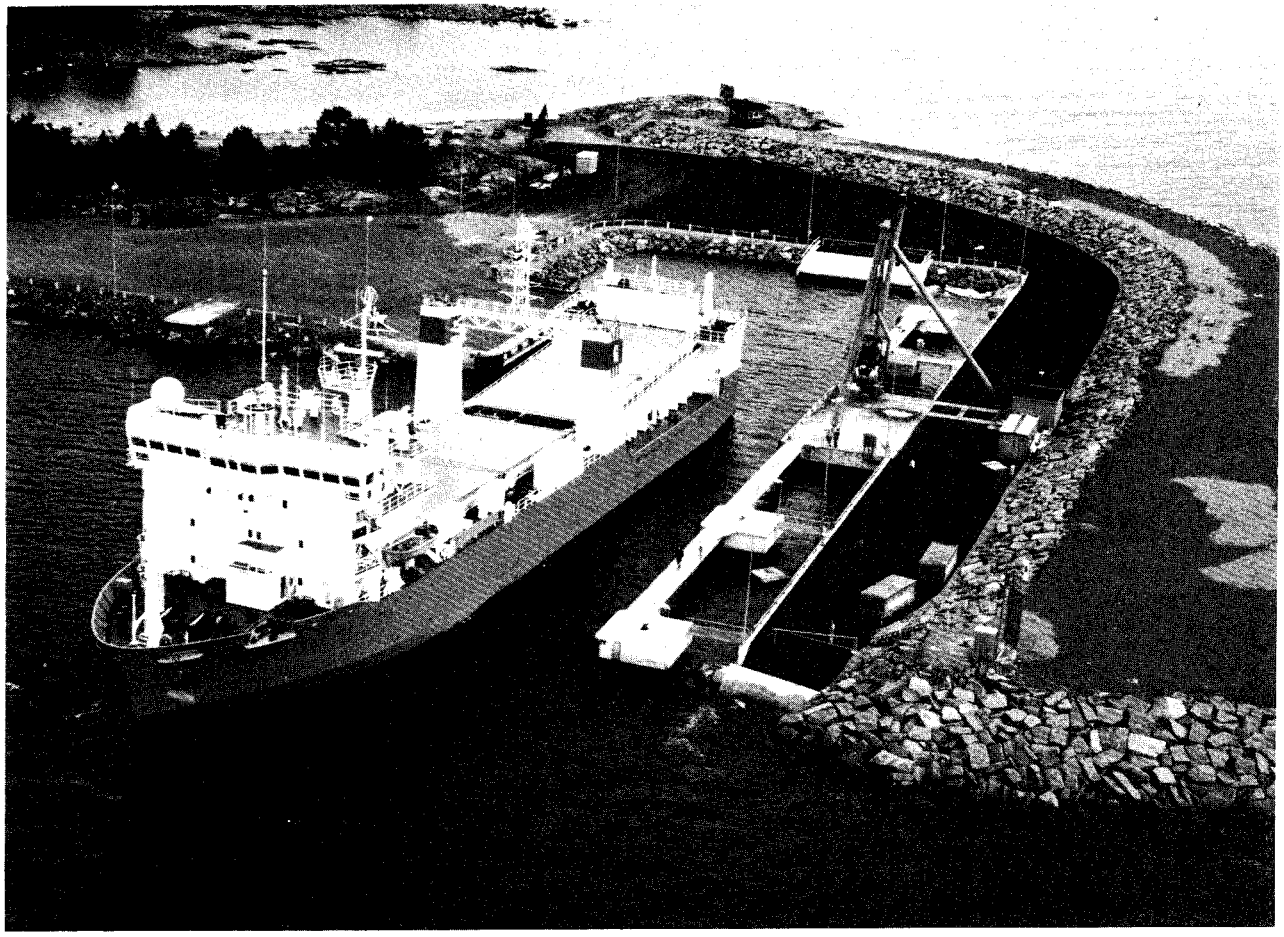


Figure 4-1. M/S Sigyn at the Simpevarp harbour outside Oskarshamn.

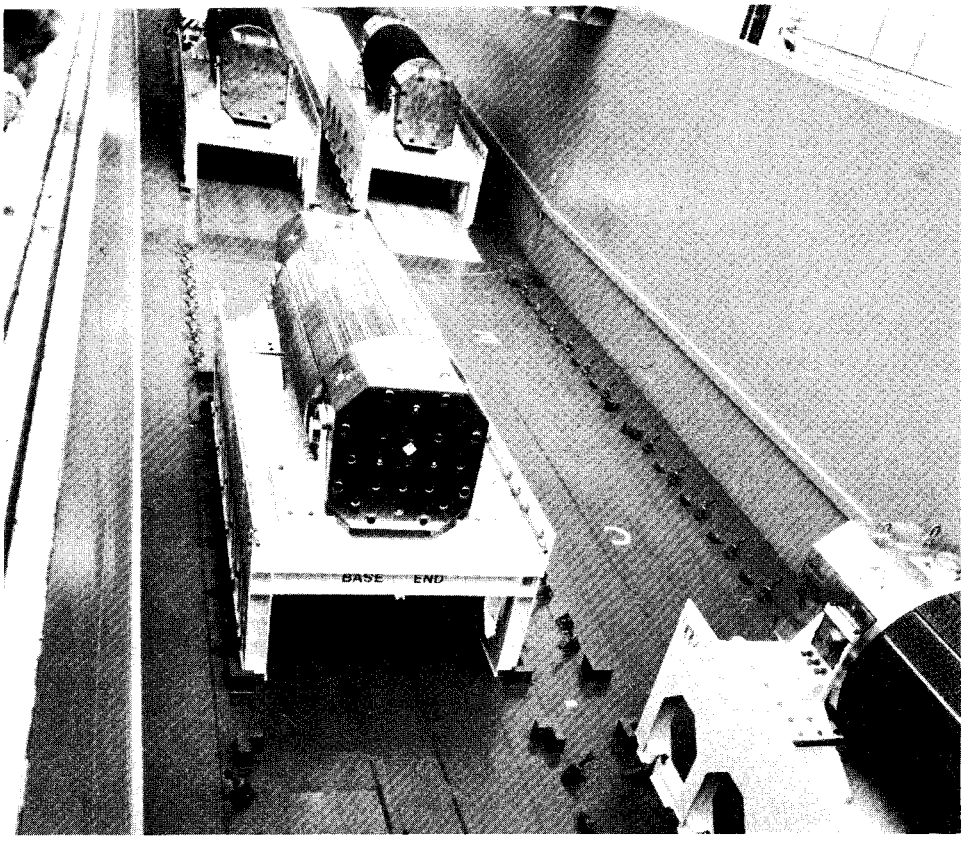


Figure 4-2. Transport flasks in the cargo hold of M/S Sigyn.

5 FINAL REPOSITORY FOR REACTOR WASTE - SFR

5.1 GENERAL

SKB is at present building a final repository for reactor waste, SFR, close to the Forsmark nuclear power plant. The repository is situated in crystalline rock under the Baltic Sea with a rock-cover of 60 m from the caverns to the sea bed. Two 1 km long access tunnels have been built from the harbour area to the repository. The first construction phase includes four 160 m long rock caverns and one 70 m high cylindrical cavern called "the silo". In a future second phase one additional silo is planned together with one or two more rock caverns (Figure 5-1).

Construction work started in summer 1983 and today all the tunnels and rock caverns in the first phase are excavated and construction of concrete structures inside the different caverns has started. After the installation of handling machines and auxiliary systems the repository will be commissioned in the beginning of 1988. The second phase of caverns is planned to be built within 10-15 years.

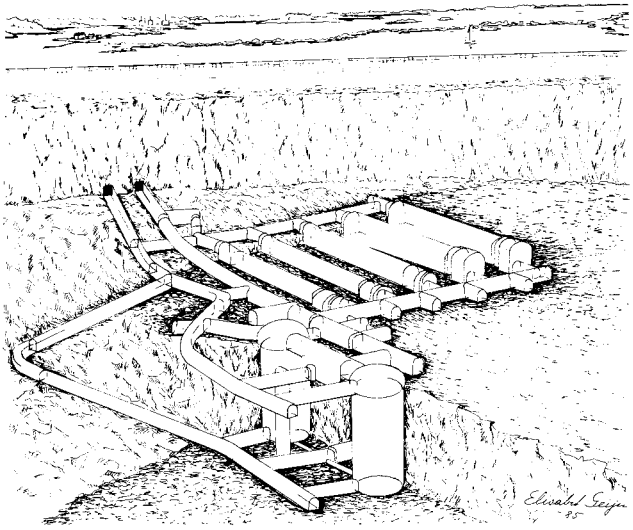


Figure 5-1. Overview of tunnels and storage chambers in SFR.

5.2 REACTOR WASTE

The waste which will be disposed of in SFR originates from the operation of Swedens twelve nuclear power plants and CLAB. This waste contains short-lived radionuclides and can be classified as low- and intermediate level waste. A small amount of similar waste from research and medical activities will also be disposed of in SFR. The total amount of waste from the Swedish program up to year 2010 has been calculated to 90 000 m^3.

All wastes are conditioned at the power plants or at the nuclear research center, Studsvik. Ion exchange resins are incorporated in either cement or bitumen. Scrap from maintenance work can also be treated in the same way if it is required. These categories are classified as intermediate level waste and calls for shielding during handling and transport. Low level waste is treated in different ways and finally enclosed in standard freight containers. The total activity content is calculated to be 3 x 10^6 GBq by year 2010. Dominating nuclides are Co-60 and Cs-137.

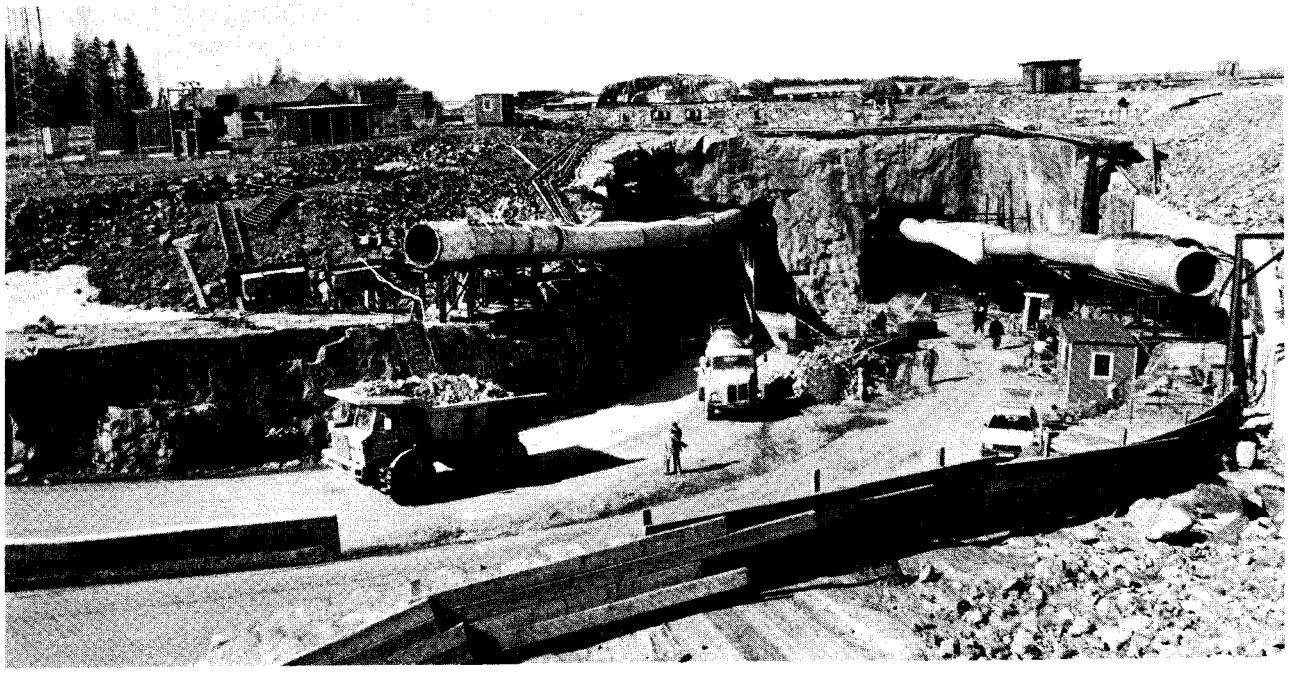


Figure 5-2. Tunnel entrances of SFR.

5.3 SAFETY ASSESSMENT

The waste containing most of the activity will be disposed of in a concrete silo, surrounded with a clay barrier. Together with the low groundwater flow in the rock under the sea this ensures a very slow release rate of substances from the waste.

The license for construction of SFR is based on a preliminary safety report. The migration of radionuclides was calculated based on pessimistic assumptions of the barrier functions. The conservatively calculated dose to the most exposed individual was 3 x 10^{-6} Sv/year.

A final safety report will be prepared for the commissioning of SFR. This report will be based on data collected from a research program carried out during the construction period including

- Geological and hydrogeological investigations in the repository area. Modelling of the groundwater flow.
- Additional tests of materials for the clay barrier around the concrete silo.
- Studies and tests of processes leading to gas production and of gas transfer properties of concrete, clay and bedrock.
- Characterization of the various waste packages which will be disposed of in SFR.
- Studies of the chemical environment in the repository and its impact on the migration of radionuclides.

Most of these investigations will be completed in 1986.

5.4 GEOLOGICAL AND HYDRO-GEOLOGICAL MODELLING

During the excavation work a lot of efforts have been made to collect data of the geological and hydrogeological situation in the area. Together with earlier geological surveys now more than 4 km of boreholes have been drilled. Geological mapping have been made of all tunnels and rock caverns. Hydrogeological tests have been performed in the boreholes and groundwater has been sampled and analysed in laboratories. The results from these investigations are continuously evaluated by a group of specialists. The data are used for a three-dimensional modelling of the hydrogeological situation in the repository area.

A progress report on this work was presented in July 1985. With that report as a base numerical modelling has been carried out. The results of these calculations indicates that the groundwater flow in the area is slower than anticipated in the preliminary safety report. The final report on this hydrogeological modelling will be ready during 1986.

5.5 DESIGN AND CONSTRUCTION

SKB has contracted Vattenfall (Swedish State Power Board) for the design and construction of SFR. In this way the personnel and other resources built up for construction of Forsmark nuclear power plant can be used. The tunnelling work started in October 1983 and the tunnels reached the repository area in the

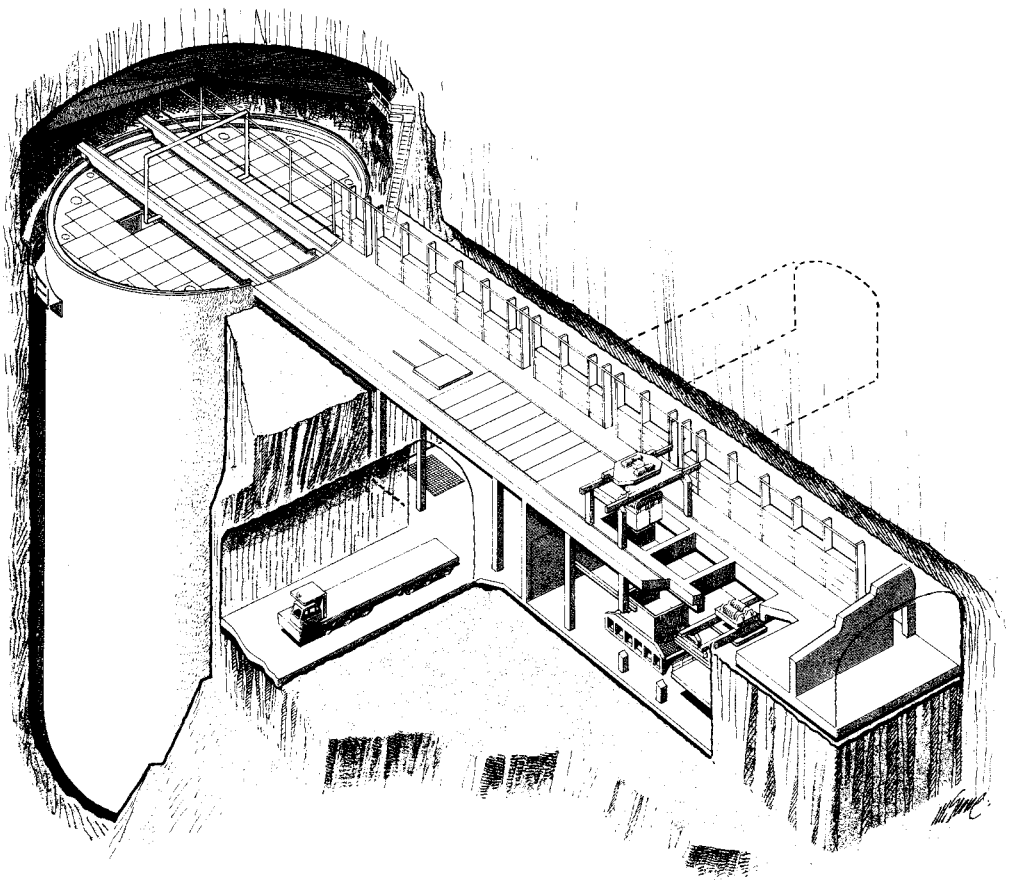


Figure 5-3. The Silo repository with remote handling of waste packages.

beginning of 1985. All tunnels and caverns in the first phase (430 000 m³) were excavated in March 1986.

In autumn of 1986 the 50 m high concrete silo will be built in the cylindrical rock cavern. The concrete silo including the internal walls will be constructed in one part by use of slipform-technique. The space between the concrete silo and the rock will afterwards be filled with bentonite. The bottom slab of one silo is founded on a layer of bentonite mixed with sand. When the silo is filled with waste the clay barrier will be completed with a bentonite/sand layer on top.

The handling of waste in the silo repository will be controlled, remotely, see Figure 5-3. A waste container arrives with an electrically driven terminal vehicle and is positioned under a handling machine. This machine runs in a tunnel above the unloading area. The container lid is removed by a remote-controlled overhead crane. The waste packages can then be picked by the handling machine and transported into the silo. After positioning in one of the shafts in the silo the waste packages are surrounded with concrete.

The same type of remote control handling will be used in one of the rock caverns. In the others conventional fork lift trucks will be used for handling of waste packages with a low surface doserate. Manufacturing of handling machines and overhead cranes has started and they will be delivered to the site in the beginning of next year.

The general design of the auxiliary systems is completed. Electrical equipment has been purchased as well as pipings for water and drainage systems. The ventilation system is also purchased and the installations will start this summer.

5.6 TIME SCHEDULE AND COSTS

SFR is planned to be commissioned in the beginning of 1988. Today all work is proceeding according to this time schedule (Figure 5-4).

The total cost of the first construction phase was earlier calculated to be 830 MSEK in current prices. Due to a lower cost escalation than foreseen the final cost is now expected to be around 790 MSEK.

5.7 SOME DATA ABOUT SFR

Table 5-1 gives some basic data about SFR.

Table 5–1. SFR-data

First construction phase 1983–1988	
Excavated rock volume	430 000 m³
Concrete structures	22 000 m³
Steel structures	600 tonnes
Buildings on ground level	28 000 m³
Buildings in rock caverns	22 000 m³
Waste storage volume	60 000 m³
Second construction phase planned 1995–1998	
Excavated rock volume	120–170 000 m³
Waste storage volume	20–30 000 m³
Operational phase 1988–2013	
Operating personnel	20–25 persons
Reception of waste	5–6 000 m³/year
Electrical power supply	4 500 kVA
Ventilation system	65–70 m³/h
Groundwater drainage	30–40 m³/h

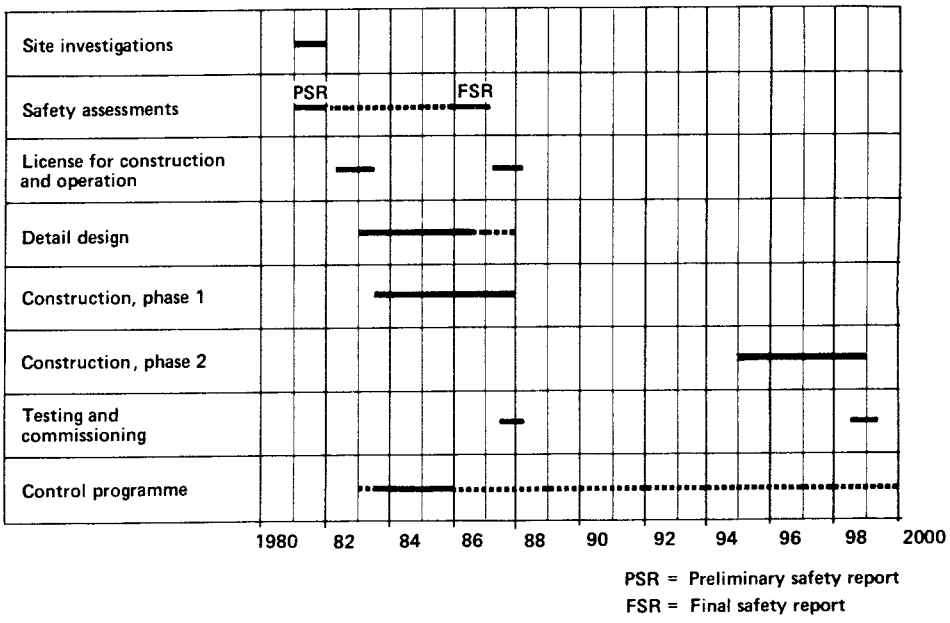


Figure 5-4. Time schedule for SFR.

6 RESEARCH AND DEVELOPMENT

6.1 GENERAL

The research and development program of SKB started in 1976-77, when a new law, the Stipulation Act, was passed by the Swedish Parliament. This law was specific to the final disposal of high level waste from nuclear power plants. It stipulated that the owner of a reactor must show to the satisfaction of the government how and where high level waste or spent nuclear fuel can be finally disposed of in a safe manner. The evidence submitted by the owner must be approved before the first loading of fuel to any new power reactor. The act thus required demonstration of feasibility of a safe disposal method but not an optimized solution. The provisions in the Stipulation Act were replaced by similar provisions in the Act on Nuclear Activities which went into force on February 1, 1984.

To fulfill the legal requirements the utilities with nuclear power plants started the KBS-project in late 1976. The project-group was later organised as a division within SKB and since January 1, 1985 the research and development program is managed by the "Division of Research and Development". The organization and staff of this division as of January 1986 is given in Appendix 1.

The main task of the R&D staff is the planning, initiation and coordination of the work and compilation and documentation of results. More than two hundred experts and consultants at universities, industry and other companies are engaged in various aspects of the R&D-work. In order to get a thorough review and discussion of results and methods as well as a constructive feedback to the program, the progress and results are published as SKB Technical reports and in appropriate scientific publications.

In 1979 and 1980, four new power reactors were granted fuel loading permits according to the Stipulation Act. These permits were based on a report (KBS1) describing how and where vitrified high level waste from reprocessed spent nuclear fuel could be finally disposed of and also on reprocessing contracts with COGEMA in France. In 1984 two additional new reactors were granted fuel loading permits this time according to the Act on Nuclear Activities. The basis was the KBS-3-report published in May 1983. This study describes a method for final disposal of unreprocessed spent nuclear fuel from light water reactors. In addition the permit was based on a program for research and development tied to the method described in the KBS-3-report.

The KBS-reports were scrutinized by a large number of reviewers both in Sweden and abroad, at the request of the Swedish government. The review process gave many valuable comments which have been taken into account in the subsequent research program.

6.2 OBJECTIVES OF THE R&D-PROGRAM

The overall objective of the SKB R&D-program is to acquire knowledge and data and to develop methods which are needed for a safe and credible disposal of spent fuel and radioactive waste at a reasonable cost.

The research done by SKB up to 1984 was mainly concerned with demonstrating the feasibility of disposal in Sweden. The efforts were concentrated on a specific method for final disposal of non-reprocessed spent nuclear fuel. The end product of these efforts was the KBS-3-report as already mentioned.

The safety analysis in KBS-3 is based on several pessimistic assumptions and methods. Circumstances, barriers and factors which are unsufficiently known are not accounted for if they work towards increased safety. Analysis methods and data are persistently chosen to give an upper limit for the calculated consequences. The method described in KBS-3 should therefore be "over-safe" in the sense that there are substantial safety margins which have not been quantified.

By well planned R&D-work the knowledge can be considerably improved in many areas of importance for the repository design and for the safety assessment. The improved knowledge could be used for

- optimization of the disposal method and accomodation to specific site conditions,
- more flexible choice of geological conditions,
- increased knowledge of real safety margins, which contributes to increased credibility.

The optimization must account for safety, economy, credibility and acceptance by society of the disposal system that finally is going to be built.

The general long range time table for the realization of a final spent fuel repository in Sweden is given in Figure 6-1. The research program is aiming at establishing a basis for a site specific license application, which would be submitted around the year 2000. By that time a system optimization should be completed and a system adapted to the site be presented.

The future evaluation with respect to safety and credibility will require a convincing site specific safety analysis, evidence that the site has the predicted and required conditions and that these conditions will prevail during a long time period.

The optimization with regard to safety and costs will require the development of simplified concepts and flexibility, in particular with respect to siting of the repository.

The previously mentioned requirements mean that all those phenomena that could affect the nuclide dispersal must be studied in sufficient detail to assess the impact on the overall safety. The dominating phenomena must in addition be described and modelled in sufficient detail that an optimal repository design can be chosen and its safety accounted for.

The following main subjects are of great importance for a repository located in Swedish bedrock and

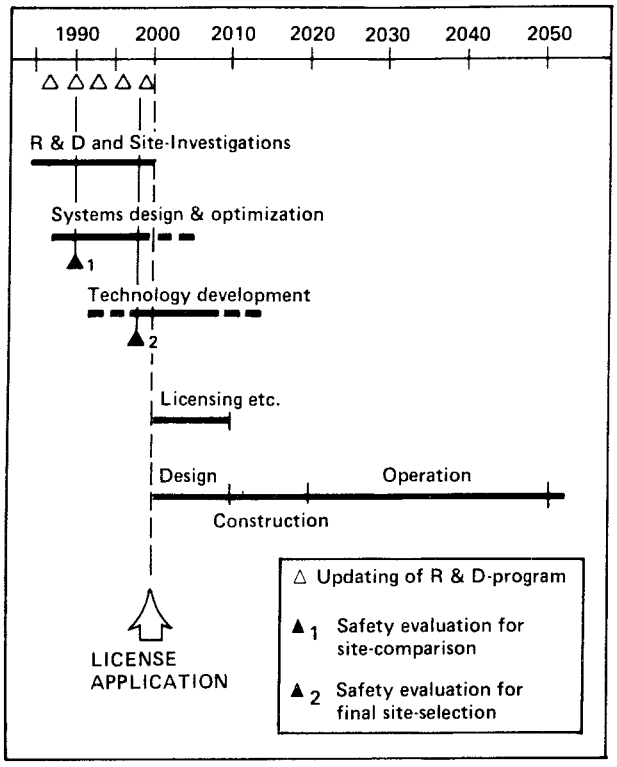


Figure 6-1. General time-table for realisation of a final repository for spent fuel.

are included in our research program:

- The stability of the bedrock.
- Groundwater chemistry and its interaction with deposited nuclear waste.
- Methods to isolate the waste or to diminish the interaction between waste and groundwater.
- Selection of site with respect to groundwater flow and radionuclide transport in the rock.
- Methods to deposit, refill and seal a repository with assurance that the materials or methods used will not degrade the isolating properties of the system.
- Radionuclide dispersal in the biosphere in order to assess the radiological consequences.

The work in the above areas is needed to understand pertinent processes, to develop models describing these processes and to assemble databases of sufficient quality.

Research is also needed in order to develop e.g.

- Methods and models for systematic analyses of barrier function.
- Instruments for geophysical and geochemical measurements.
- Methods for fabrication and/or application of engineered barriers and for quality control.

The planning of the research program is made with the following subgoals enroute to a siting permit. See Figure 6-2.

1. After 1990 2-3 sites should be selected for detailed investigations, which are needed for a siting permit. On at least one of these sites a shaft must be constructed. The detailed investigations including shaft construction will take 5-7 years.
2. About 1995 the final system and materials for engineered barriers should be selected. This would then be the basis for any in-situ-demonstration-test that may be required.
3. About 1998 at least one site specific system optimization should be completed.
4. About 2000 a preliminary safety report should be completed as a basis for a siting permit application.

For the short term and during the next five years this means

- that the preliminary site investigation program on about 10 different typical sites must be completed. Rock-types and sites which are of any interest from various points of view should be represented in this program,
- that the development of models and methods for systematic safety assessment should reach a level where different sites could be compared in a meaningful way with respect to properties important for safety. This means particular emphasis on models for groundwater flow,
- development of program, methods and instruments which are needed for detailed site investigations during the 1990-ies,
- research on alternative materials and methods for engineered barriers,
- studies of repository design in order to evaluate possibilities to adapt various alternatives to local geological conditions at different sites.

As the spent nuclear fuel, the groundwater and the crystalline bedrock are components of any possible design of the repository the research program must also include studies of these components and interaction between them.

6.3 INTERNATIONAL COOPERATION

Cooperation and exchange of information on an international or bilateral basis is an integrated part of the R&D-activities of SKB.

International development in the field has been followed through participation in a number of conferences, where papers by SKB or its consultants have been presented, see Appendix 2. Staff member of SKB and experts engaged by SKB have also participated in activities within the IAEA and the OECD/NEA.

SKB has bilateral information exchange agreements with USDOE, AECL-Canada, NAGRA-Switzerland and CEA-France. A similar agreement with Euratom has been concluded and will be signed in early 1986. Information exchange without formal agreements has been made with organisations in the Federal Republic of Germany, Belgium, United Kingdom, Japan and Finland.

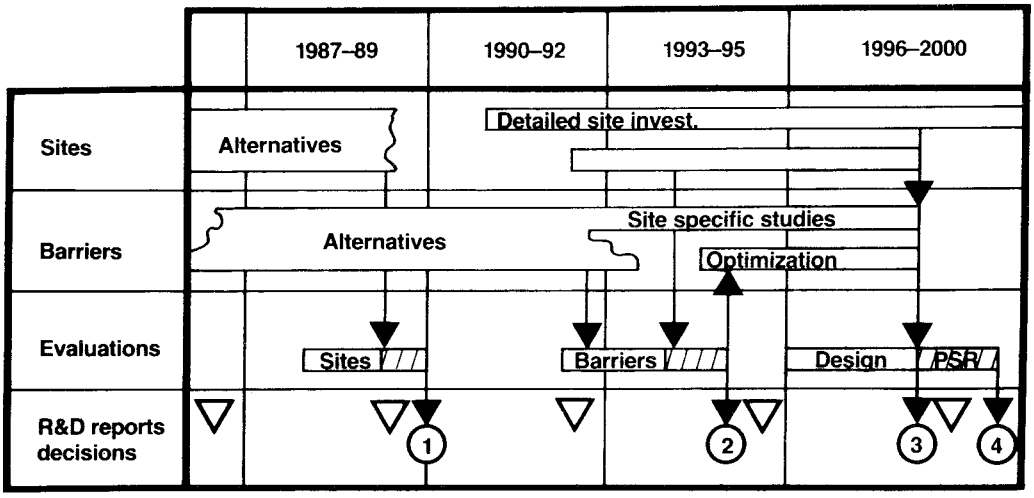


Figure 6-2. Timetable for selection of repository system and site.

During 1985 Swedish specialists and consultants to SKB worked for longer or shorter periods at research laboratories in France (CEA, Fontenay aux Roses) and USA (Lawrence Livermore Laboratories, Colorado School of Mines). In a similar way foreign experts have been working at Swedish research institutions within the framework of the SKB Research program.

The multinational OECD/NEA project at Stripa, managed by SKB, has progressed according to schedule and a proposal for a phase 3 of the project is now being prepared. The following countries are participating in the Stripa project: Canada, Finland, France, Japan, Spain, Sweden, Switzerland, United Kingdom and the United States. See further Chapter 16 of part II.

The phase IV of the JSS project for studies of radioactive glass jointly sponsored by CRIEPI, Japan, NAGRA, Switzerland and SKB, Sweden has been running according to plans and most of the experimental work is finished. A final phase V of the project is being discussed. See further Chapter 10 of part II.

SKB is participating in the international HYDROCOIN-project which is coordinated by a secretariate set up by the Swedish Nuclear Power Inspectorate and OECD/NEA.

In 1985 the Materials Research Society's Ninth International Symposium on the Scientific Basis for Nuclear Waste Management was organized by SKB, and was held September 9-11, in Stockholm. This symposium was the second one in this series held in Europe and it replaced the annual symposium, since 1978 included in the Materials Research Society's Fall Meetings in Boston. This series of symposia is widely recognized for providing a unique opportunity for an international gathering of scientist of different disciplines for discussions on the scientific basis for nuclear waste management. At the Stockholm meeting 93 papers were presented to 275 participants from more than 10 countries. The presentations covered practically all materials science aspects of nuclear waste management research.

Besides the Materials Research Society and SKB, the symposium was sponsored by:

U.S. Department of Energy
U.S. Nuclear Regulatory Commission
The Swedish National Board for Spent Nuclear Fuel
The Swedish Nuclear Power Inspectorate
The National Institute for Radiation Protection

6.4 SUMMARY OF RESEARCH ACTIVITIES DURING 1985

The main research activities during 1985, as for the previous year, are part of a program based on the experiences from the KBS-3 study and the comments received in the review of that report. In addition some studies related to alternative concepts to KBS-3 have been initiated.

A comprehensive description of the research and development in different areas is given in part II of this report. A brief summary is given below.

6.4.1 Materials

Experimental studies of spent fuel leaching is an important part of the program. The experiments are made mainly at Studsvik, where additional equipment

for characterization and examination of spent fuel has been installed. SKB also continues to organize annual workshops on spent fuel with participation of specialists from those countries that are active in this area.

The experiments have indicated that the uranium concentrations in solution are solubility controlled and further studies of the importance of solubility constraints in spent fuel leaching have been started under both oxidizing and reducing conditions.

Studies on waste glasses are being continued within the JSS-project. They include experimental as well as theoretical studies of waste glass leaching under repository conditions.

Studies on possible canister materials have, in the SKB-program, been concentrated on copper. During 1985 further studies on the Hot Isostatic Pressure-process (HIP) have been made. They have concerned the modelling of the HIP process and metallographical studies of the copper material produced through HIPing.

6.4.2 Engineered barriers, design and technology

No specific studies on repository design have been made. However, alternative concepts for final disposal have been reviewed by SKB during 1985 as a preparation for setting-up the new R&D-program that will cover also alternatives to the KBS-3 concept.

The "Buffer Mass Test" in Stripa was completed in 1985. The experiment has shown that the bentonite fills all voids after water saturation and swelling. Previously obtained laboratory data have thus been verified.

The canister settlement in a deposition hole filled with dense smectite clay has been studied theoretically and experimentally. Theory and experiments are in good agreement. A settlement of less than 1 centimeter in a million years is predicted. Further testing over a longer time-period at 70°C is planned.

Preparations have been made for experimental studies of tectonically induced shear of a canister in a deposition hole.

Promising pilot-tests have been made in sealing water-bearing fractures by injection of clay and cement slurries.

6.4.3 Chemistry

The research in this field spans over a wide range of chemistry-related areas like groundwater chemistry, radionuclide chemistry, nuclide transport modelling and validation of models by help of natural analogue studies.

The quality of groundwater sampling and analysis has improved considerably after the introduction of a mobile field laboratory in connection to downhole water sampling and measurements.

Hydrochemical investigations in crystalline bedrock in relation to existing hydraulic conditions at the test sites have been reexamined. Hydrogeological conditions have a strong influence on the sample quality. The results of this examination will be used to guide further improvements of sampling equipment and data evaluation.

Geochemical calculations of the effect of heat on the minerals in the near-field have been made. In particular, no evidence for an evolution of bentonite to an illite type of clay was detected in calculations for 25°C and 100°C.

The solubility and speciation of actinides like neptunium and plutonium are being studied in cooperation with the French CEA.

The importance of colloides, organic complexes and microbes for the migration of radionuclides is being investigated. Studies on sorption and diffusion phenomena in migration processes are also continued. A considerable amount of experimental evidence have now been accumulated on the diffusion properties of the micropore system in crystalline rocks.

The theoretical modelling of radiolysis effects is being tested against evaluated examples and experiments.

The chemistry of radionuclides in concrete is given increased attention in view of that concrete might be used as an alternative backfill material.

A further development of nuclide transport models is being made. Channeling effects and their importance for the dispersion of radionuclides have been studied. Coupling between geochemical and hydrological models is also studied.

Validation of transport models and the phenomena they imply is an important area for research. Laboratory experiments, in situ tests and natural analogue studies are being used to study important phenomena and to compare with model predictions. Much of this work is being made and planned in international cooperation and it may be foreseen that efforts in this area will continue to increase. Results will provide a basis for enhanced confidence in model predictions and long-term safety assessment.

6.4.4 Geoscience

Site-characterisation studies have been continued and one new site, Klipperåsen, has been almost completed during 1985. Some studies related to gabbroic rock have also been made. Start of drillings at the Kolsjön site (gabbro) have so far failed due to public opposition.

A 4-year program on studies of fracture zones has been initiated. The ultimate aim is to get an improved understanding of the importance of fracture zones for nuclide transport from repository depth to the environment. Field studies have been started at the Finnsjö area and at Ävrö in the Simpevarp area.

The application of radar techniques have been further developed and improved. Penetrations up to 160 m have been achieved under favourable conditions.

A dilution probe for measurement of natural groundwater flow at depth in boreholes has been developed.

The important task of modelling groundwater flow

regimes is given special attention. Existing models are being used in intercomparison and validation projects like at URL, Canada and in the international HYDROCOIN-project. Studies of statistical methods in hydromodelling and data evaluation are also underway.

6.4.5 The biosphere

Biosphere characterization and measurements of natural radioactivity have been performed at two study sites, Bjulebo and Klipperåsen.

To study the natural ageing in groundwater recipients the investigations of changes in physical and chemical characteristics of lakes and Baltic bays with time have continued during 1985.

6.4.6 Safety evaluations

During 1985 the work in the area of safety and performance assessment has continued along the lines layed down after the finalization of the KBS-3 study. That imply the development of performance assessment tools satisfying a set of different needs for making R&D priorities, design optimization, site screening/ranking and repository licensing.

A probabilistic systems analysis code (PROPER) is being developed by SKB. During 1985 work on the PROPER code has concentrated on the development of an efficient executive program and simplified submodels for the near-field and the far-field.

Also, further development of the comprehensive assessment models used in KBS-3 as well as new ones is taking place. Continuous improvement of the quality and the documentation of models, computer codes and programming is also an important part of the program.

6.4.7 The Stripa project

The Phase 2 of the international Stripa project, running since 1983, is planned to be completed in 1986. Currently, negotiations are under way regarding a five year prolongation, Phase 3, of the Stripa project, starting in 1986.

During 1985 the research at Stripa has been concentrated to the following areas:

- detection and characterization of fracture zones,
- radionuclide migration and groundwater characteristics,
- behaviour of bentonite clay as a backfilling and sealing material.

The possibility to perform large scale experiments under realistic conditions at Stripa and the development of instruments and methods within the Stripa project continues to be of great importance for the SKB-program on nuclear waste disposal.

6.4.8 Documentation

A computerized data base is under development at SKB. It will contain data generated at the geological site-investigations and projects within the R&D-program. One of its aims is to systematically collect and store data sets in a common data base, that is readily available to scientists doing R&D- and assessment work.

7 SYSTEM PLANNING AND COST CALCULATIONS

7.1 SYSTEM PLANNING ACTIVITIES

The waste management system described in Chapter 1 is the basis for the planning of the work to be performed within SKB, concerning R&D and Facilities. As some of the steps will not be implemented until 30 years from now changes in the system are very probable.

Within the division of Planning and Systems Analysis studies of possible changes in the system are made, primarily with respect to their impact on the technical solution and on the costs. The safety aspects are covered by the R&D-division. The purpose of the studies is to find a system design that, while fulfilling the safety requirements gives an acceptable total cost.

7.2 REPROCESSING

SKB and the Swedish utilities have concluded agreements with COGEMA and BNFL for the reprocessing of a total of 729 ton uranium. This corresponds to less than 10% of the total amount of fuel scheduled to be used within the Swedish program.

For the remaining 90% the plan has been to do direct disposal without reprocessing. Two important milestones on this route have been the construction of the CLAB and the approval by the government of the KBS-3 method for direct disposal of spent fuel.

This once-through strategy has been judged to be the most rational and cost-effective solution in Sweden under the prevailing conditions. It is also, at present, the politically preferred option.

To simplify the system and to avoid to build separate facilities to take care of the waste from reprocessing, SKB is now actively trying to transfer the reprocessing contracts with COGEMA to other customers. In 1985 178 tonnes were transferred to a Japanese utility.

With the same purpose an agreement has been made with four utilities in the Federal Republic of Germany to exchange fuel. The German utilities will take over the 57 tonnes of Swedish spent fuel presently

stored at La Hague awaiting reprocessing. In exchange SKB will receive 24 tonnes of Mixed Oxide (MOX) fuel for interim storage in CLAB and subsequent final disposal. The licensing procedure for the exchange is in progress.

7.3 COST CALCULATIONS

7.3.1 Plan-85

According to Swedish law all costs for the management of radioactive waste, including the decommissioning of the nuclear power plants, have to be born by the owners of these plants. The costs are covered by a fee determined annually by the government.

The basis for the fee is a cost calculation of all the activities for the back-end of the nuclear fuel cycle, which is carried out by SKB each year /7-1/. The cost calculation is based on the scenario for the back-end activities described in Chapter 1.3. The cost calculations include the costs for construction, operation and decommissioning of all necessary facilities and equipment. These are:

- Transport system;
- Interim storage for spent fuel, CLAB;
- Interim storage for reprocessing wastes;
- Encapsulation station;
- Disposal facility for spent fuel, high level waste and other long-lived wastes;
- Disposal facility for reactor operation wastes and decommissioning wastes, SFR.

Also included are the costs for R&D, for reprocessing services (for 690 ton U), and for the decommissioning and dismantling of the nuclear power plants.

The estimated future costs, at the price level of January 1985, are about SEK 42 billion. Up to and including 1985 already SEK 4.3 billion have been spent. This figure includes costs for CLAB, SFR and the transportation system as well as for reprocessing services and the R&D-program. The total cost for the back-end of the nuclear fuel cycle in Sweden is thus about SEK 46 billion. The value of the corresponding electricity produced at the nuclear power plants is about SEK 500 billion.

Many of the costs will be incurred fairly far in the future. The total expenditures will be spread out over a period of more than 70 years. Figure 7-1 gives a rough account of the distribution of costs in time.

If the reprocessing costs are excluded, the breakdown of costs is roughly:

Transportation of wastes	7%
Interim storage of spent fuel	20%
Encapsulation and final disposal of spentfuel and long-lived wastes	34%
Final disposal of operational and decommissioning wastes	4%
Decommissioning and dismantling of nuclear power plants	27%
Miscellaneous incl. R&D and pilot facilities	8%

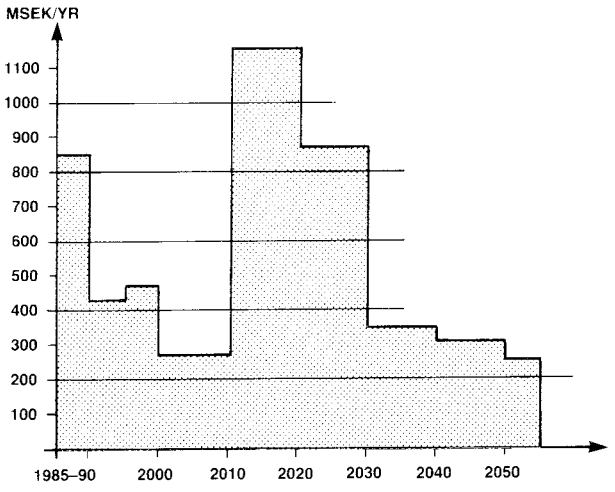


Figure 7-1. Approximate distribution in time of future waste management costs for Sweden's nuclear power program.

The cost calculations are based on a preliminary design of the different facilities. In this work the experiences gained from the construction of the CLAB and SFR facilities are very valuable as background for the cost data.

7.3.2 Waste management fee

Based on the cost calculations the government has decided that the fee for 1986 should be SEK 0.019/kWh, which corresponds to a total cost for the Swedish nuclear utilities of SEK 1.2 billion/year. The same fee was used in 1985. The fee is paid into funds, one for each utility, at the Bank of Sweden. The funds are administered by the state authority, SKN (The National Board for Spent Nuclear Fuel), which also allocates money from the funds to the various waste management activities performed by SKB.

7.3.3 Variation analysis

The cost calculations that are made to establish the fee are generally based on very cautious assumptions about the waste management system, e.g. no credit is taken for possible cost reductions that can be achieved through scientific and technological development. A potential, however, exists for actual cost reductions when the different parts of the system will be realized. To investigate this potential, cost calculations are also made with changes in the assumptions about e.g.:

- location of encapsulation and disposal facility;
- lay-out of disposal facility;
- encapsulation method and material;
- heat generation and its distribution in the repository;
- time schedule.

These studies also have the purpose of giving advice to the R&D-planning.

7.4 DECOMMISSIONING

The costs for decommissioning and dismantling the nuclear power plants make up about 1/4 of the total back-end costs. This figure is based on an old study. During 1985 SKB initiated a new decommissioning study, the results of which will be included in the 1986 cost calculations. The study covers all the Swedish reactors and is performed by a working group from the utilities.

SKB is presently not doing any R&D-work on decommissioning. As all the commercial nuclear power plants will be in operation for more than 20 years still, the development of special methods and equipment will not begin until the turn of the century. To follow the development in other countries, however, SKB is engaged in an international cooperative program sponsored by the OECD/NEA.

7.5 TIME SCHEDULE

The present time schedule for the waste management in Sweden is based on the assumption of 40 years interim storage of the spent fuel in CLAB before disposal. This means that encapsulation and disposal will start around 2020. This time schedule could be changed and a study has been made of the impact of possible changes on the planning, safety and costs /7-2/.

It was found that with regard to the time necessary for site investigations, optimization of design and licensing, it would be feasible to start disposal already around 2005, i.e. 15 years earlier. Such a change in the time schedule would not affect the safety of the system.

It was also shown that the interim storage period for the spent fuel could probably be prolonged to at least 100 years without any effect on the safety.

The total costs for the waste management system was found not to be very sensitive to changes in the time schedule. The increasing storage costs are offset by decreasing disposal costs.

It was thus concluded that the present time schedule gives a reasonable starting point for the planning of the activities necessary before start-up of the final disposal.

8 CONSULTING SERVICES

The achievements in the Swedish nuclear waste management program have raised an international interest. This interest has focused on the findings reported from the KBS project and on the implementation of CLAB, SFR and the transport equipment as parts of a total back-end system. With regard to this international interest in Swedish know-how and experience in the nuclear waste management field the owners of SKB in 1984 decided to organize a small group within the company for marketing and coordinating consulting services.

Through cooperation with the different specialized associated groups and individuals, which have contributed to the Swedish program for several years, it is possible to offer services in almost every discipline involved. The scope of services covers theoretical studies and laboratory work as well as field investiga-

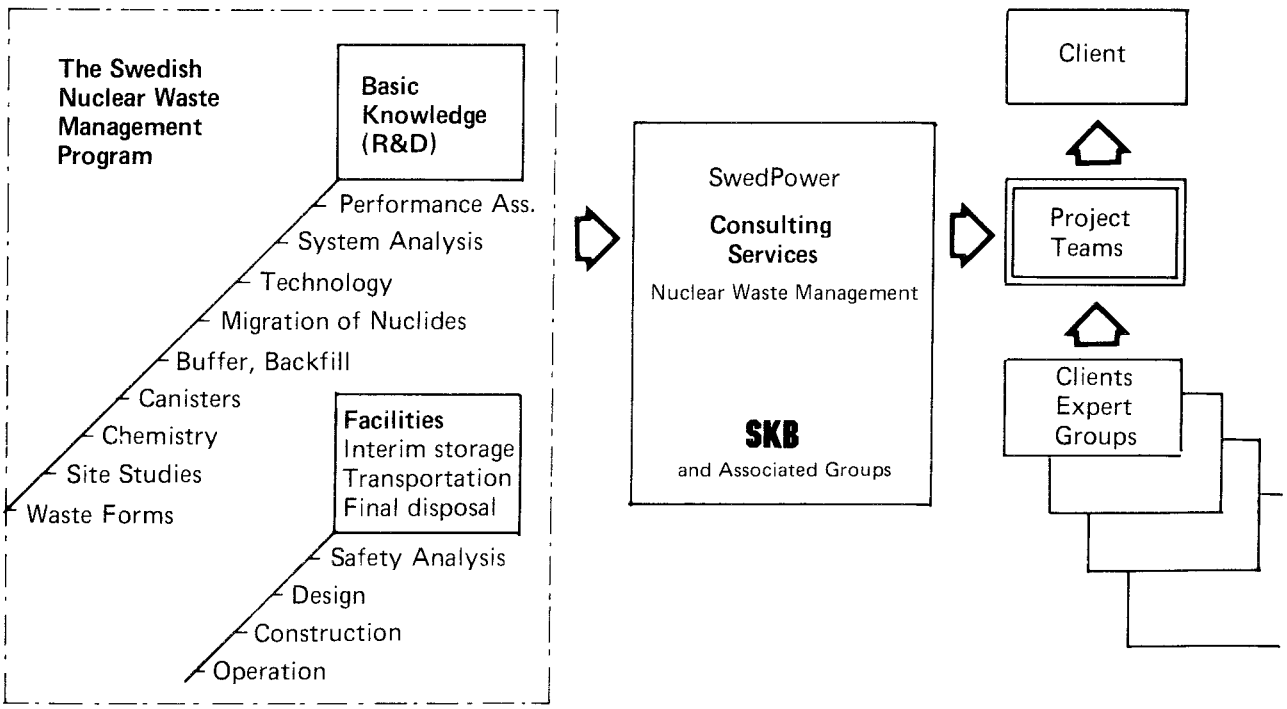


Figure 8-1. Organisation of consulting services.

tions including the supply of advanced instrumentation and evaluation of results. Also services regarding licensing, design, construction, commissioning and operation of waste facilities are included in the scope.

Beside the commercial interest a main reason for starting up the consulting activities within SKB has been the possibility to stimulate an improvement and broadening of the knowledge and experience among the groups involved.

SKB has an open and extensive international information exchange based on bilateral agreements with corresponding organizations in other countries (see Chapter 6.3). SKB regards this information exchange as very important and will carefully avoid that commercial interests shall disturb this open exchange.

From 1986 the consulting services from SKB and Associated Groups will be coordinated with the consulting activities of SwedPower. SwedPower has the same main owners as SKB and markets know-how and experience in the entire energy field. This coordination will strengthen SKBs competence and capacity, specially regarding facility design, construction and operation.

The general principles for the organization of consulting services based on the Swedish know-how and experience in the nuclear waste management field is shown in Figure 8-1.

Marketing activities and discussions with potential clients have so far been a considerable part of the work.

Umbrella agreements for consulting services have been signed with Industrial Power Company Ltd (TVO) in Finland and Taiwan Power Co., Taiwan. Some assignments have been accomplished also in Switzerland and USA.

9 INFORMATION AND PUBLIC AFFAIRS

9.1 GENERAL

The Swedish system for handling and disposal of radioactive residues is planned and designed to meet a very high standard in terms of occupational health and safety and environmental impact. It also satisfies the requirement that no undue burden should be laid on future generations and that only proven techniques should be used.

The nuclear debate and the parliamentary decision have contributed to the fact that Sweden today has developed a fairly complete system for the back-end of the nuclear fuel cycle, not only from a technical point of view, but also with regard to legal, administrative and financial aspects.

Information to the public concerning facilities and the safety of the systems is a very important part of the waste management program. The most crucial issue at present is the decision on detailed site investigations. In order to achieve acceptance of the site for a final repository at the end of the 1990s extensive information will have to be furnished both locally and on a national level.

According to recent polls of public confidence there is almost an equilibrium between those who believe that the radioactive waste can be safely handled and disposed of and those who think it cannot. This is an improvement compared to earlier surveys.

Although Sweden has more positive figures in this respect than most other countries, the implementation of the waste management system will not be possible unless it is accepted by the general public.

9.2 SKB INFORMATION ACTIVITIES

SKB has already since it started its R&D-program on waste disposal in 1977 informed the public on its activities. The aim has been to give a clear and balanced description of the main issues concerning nuclear waste and its disposal.

During 1985 a department of public affairs has been established within SKB in order to broaden the general information about SKB activities and their relation to the Swedish nuclear power program. A coherent information program for the future is now being worked out. It is based on the awareness that the public is entitled to open and clear information about handling and disposal of nuclear waste, as well as about the plans and program of SKB.

Great interest has been shown by the press for the SKB activities. Press conferences were arranged at the start-up of CLAB on July 11th, on June 4th at the STRIPA symposium, which was arranged by OECD-/NEA and SKB in Stockholm, and at a ceremony when M/S Sigyn was reregistered to sail under Swedish flag.

There has also been a number of interviews and programs on Swedish radio and television with the participation of SKB.

A large number of visitors have been received at the SKB facilities (CLAB, Stripa and SFR) during the year, amongst them more than 50 groups of foreign specialists. Schools and the general public have also frequently visited the facilities.

Information material such as brochures, video films etc is being produced on a continous basis. Available brochures and videofilms in English are listed below.

Brochures

* SKB - Activities
* SKB - SFR Final Repository for Reactor Waste
* SKB - CLAB Central interim storage facility for spent nuclear fuel
* M/S Sigyn
* STRIPA a deep underground research facility for nuclear waste disposal
* Data on nuclear power and waste

Videofilms

* Progress of the Stripa Project
* A Final Repository at Forsmark
* CLAB in Action - Central Storage for Spent Nuclear Fuel
* Looking deep into the rock (describes geological site-investigations)

REFERENCES PART I

CHAPTER 1

1-1 NEW SWEDISH NUCLEAR LEGISLATION

Swedish ministry of industry DSI 1984:18.

CHAPTER 7

7-1 PLAN-85. KOSTNADER FÖR KÄRNKRAFTENS RADIOAKTIVA RESTPRODUKTER

(Costs for the Radioactive Residues from Nuclear Power). Svensk Kärnbränslehantering AB June 1985 (In Swedish).

7-2 ALTERNATIVA TIDPLANER FÖR HANTERING AV ANVÄNT KÄRNBRÄNSLE

Konsekvenser för planering, säkerhet och kostnader (Different Time-Schedules or the Management of Spent Nuclear Fuel. Consequences on Planning, Safety and Costs). Svensk Kärnbränslehantering AB December 1985 (In Swedish).

SKB ANNUAL REPORT 1985
Part II

Research and Development During 1985

CONTENTS OF PART II

10 MATERIALS

10.1 SPENT FUEL

As for 1984, the main activities on wasteforms have also for 1985 been concentrated on spent fuel. The close contacts with other groups in the world performing similar studies have continued. This year the annual workshop on spent fuel, the fifth one in the ongoing series, was held in Sweden and arranged by SKB.

A series of spent fuel leaching experiments were started in Studsvik 1982. These experiments are now nearly finished although several specimens are still exposed to distilled water and groundwater after accumulated contact times exceeding 1,200 days. In addition to these studies, experiments aiming at elucidating the importance of solubility constraints and radiolysis have been completed /10-1, 10-2/.

New equipment necessary for characterization and examination of spent fuel with respect to its leaching performance has now been installed in Studsvik.

10.1.1 Solubility constraints

The spent fuel leaching experiments have indicated that the uranium concentrations in solution are solubility controlled. Even after contact times exceeding 1,000 days, the measured concentrations are in the range of 1-2 ppm, i.e. the same as after only a few weeks contact time, see Figure 10-1. In order to check the observed apparent solubilities, a replenishment experiment was designed. Fuel segments as well as two fractions of fuel fragments were exposed to synthetic groundwater and at preset times 20% of the solution was removed and the leach vessels were replenished with virgin solution. The results are shown in Figure 10-2.

As can be seen in the figure, the Cs curves display, as expected, the initial release of about 1% of the inventory, whereupon the measured concentrations almost follow the 20% successive dilution curve (indicated as a dashed line in the figure). It should also be observed that there is no marked difference in Cs release between the fuel fragments and the fuel segments, i.e. the specimens where the fuel/clad gap inventory is present.

The uranium results are somewhat surprising. For the fuel fragments, the leach fractions agree well with previous observations, while the fuel/clad segments showed increased dissolution of U initially and then concentrations in solution decreasing roughly following the 20% dilution curve. This is believed to be due to increased surface oxidation of the segment specimens, having been stored in air for two years prior to leaching.

As the results of the experiments were, in some respects, indecisive, new studies of the importance of solubility constraints in spent fuel leaching have been started.

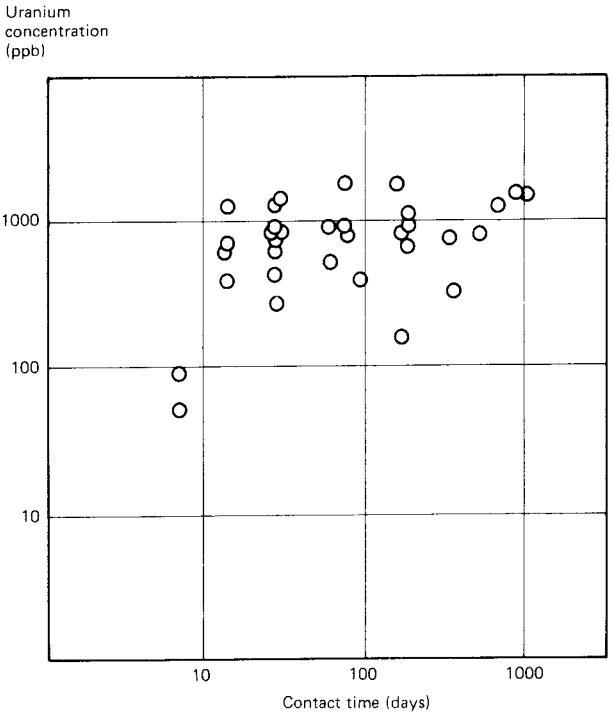


Figure 10-1. Measured concentrations of uranium in leach solution centrifugates as a function of time.

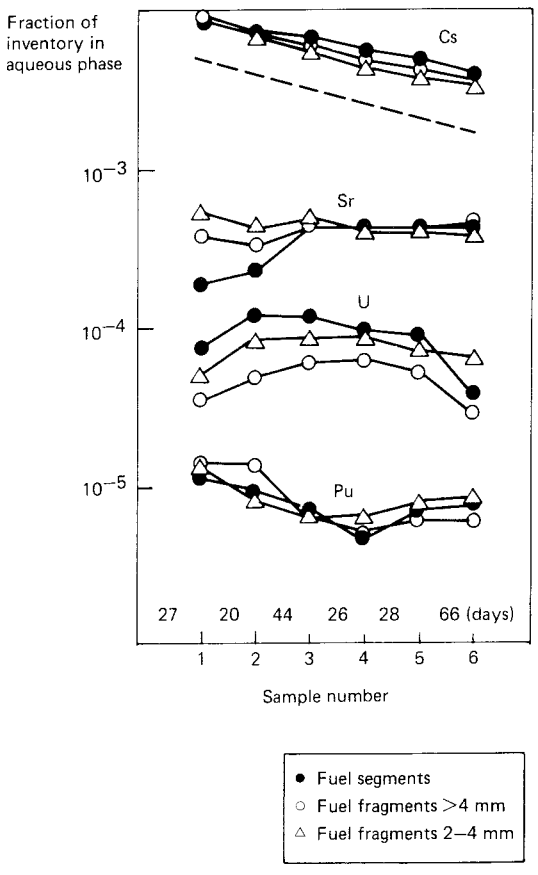


Figure 10-2. Replenishment experiments: Variation of leach fraction with successive replenishment. (Fuel segments are cut from a fuel pin and include both fuel and zircalloy cladding. Fuel fragments consist of spent fuel without cladding.)

10.1.2 Low burnup fuel: α-radiolysis experiments

Although deep granitic groundwaters are expected to be highly reducing, it has been postulated that local oxidizing conditions, caused by α-radiolytic decomposition of water, may be created in a thin aqueous film adjacent to the fuel surface, giving rise to a dissolution of the fuel under oxidizing conditions.

Table 10-1. Comparison of ARL values for "α-radiolysis" experiments under oxidizing and reducing conditions.

ALR (FIAP/d) (x 10^6)				
Contact time (d)	22	15	28	55
Oxidizing conditions				
U	5.1	3.9	3.7	2.5
Cs-137	23.6	6.8	4.9	3.9
Sr-89	5.2	5.6	4.1	2.6
I-131	4.1	4.1	4.1	2.6
Ba-140	3.9	4.4	2.7	1.4
Pu	1.0	1.0	1.0	1.0
Reducing conditions				
U		0.04	0.03	0.04
Cs-137		1.6	0.8	0.7
Sr-89		0.36	0.24	0.21
I-131		1.7	ND	ND
Ba-140		0.53	0.39	0.22
Pu		0.05	0.02	0.07

ARL = Apparant leach rate
FIAP = Fraction of inventory in aqueous phase

In a first experiment to study the influence of α-radiolysis, comparative investigations were performed using low burnup fuel (0.5 MWd/kgU). This iow burnup fuel had about the same ß- and γ-activity as the high burnup fuel, but an α-activity about two orders of magnitude lower.

The results for oxidizing and reducing conditions (obtained using H_2-gas and palladium catalyst) are presented in Table 10-1 as apparent leach rates. Inspection of the results lead to the following conclusions:

a) The measured U concentrations were higher than expected from comparison with high burnup fuel.
b) Cs, Sr, I and Ba appeared to dissolve congruently with the UO_2 matrix.
c) The decrease in leach rates under reducing conditions were of the same order as those obtained with the high burnup fuel.

At present it seems unlikely that the presence (or absence) of α-radiolysis can be advanced as the cause of these observations.

10.2 WASTE GLASS

The studies of waste glasses are performed almost entirely within the JSS-Project. (A joint project between SKB, NAGRA, Switzerland and CRIEPI, Japan.) The last remaining SKB studies in support of the JSS-Project have been completed and reported /10-3, 10-4/.

10.2.1 JSS-project

The Phase II of the project has been completed and reported /10-5/. The Phase II contained studies on the interactions between glass and bentonite and steel corrosion products. These studies are now continued in Phase IV. The general conclusion to be drawn from Phase II is that the effects of additional products in the near field must be investigated more specifically before any long range predictions of waste glass behaviour under repository conditions can be made. This is now being done in Phase IV.

Phase IV involves the development of a predictive model for glass dissolution under repository conditions. This work is still going on, and updates of the status as well as the experimental background are given in /10-6/ and /10-7/. As to date the model has been developed to include leaching of a highly radioactive glass in the presence of bentonite. The model is based on two submodels: a thermodynamical model for glass corrosion in groundwater and an equilibrium model (ion exchange, solubility) for the bentonite/water system. Rate and stability constants and potential secondary alteration products are derived from a thermodynamic and kinetic analysis of experimental results. Using these data, both submodels describe adequately the experimental reality for a variety of repository conditions as can be seen in Figures 10-3 and 10-4.

Preliminary studies of using natural basaltic glasses as natural analogues for long-term validation of the model have also started /10-8/.

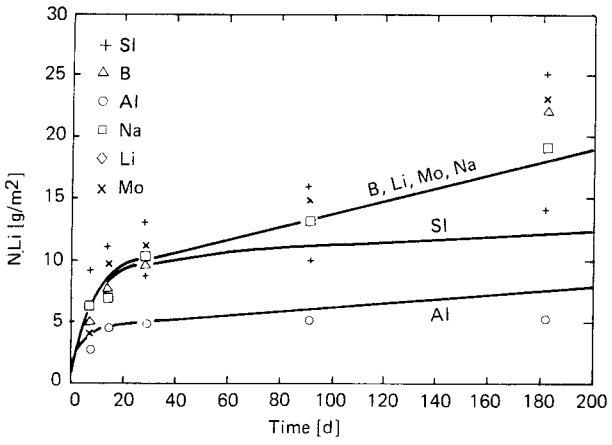


Figure 10-3. Comparison of leach results of JSS glass in deionized water (MCC-1 test, 90°C, 10 m^{-1}) with the computer simulation (solid lines).

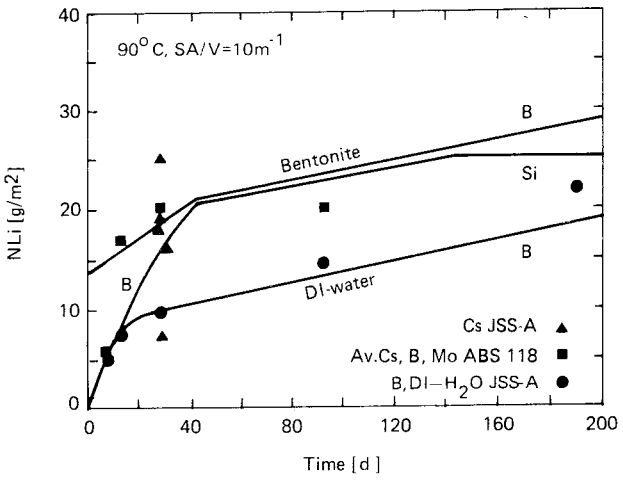


Figure 10-4. The effects of bentonite on glass leaching: model (solid lines) and experiment.

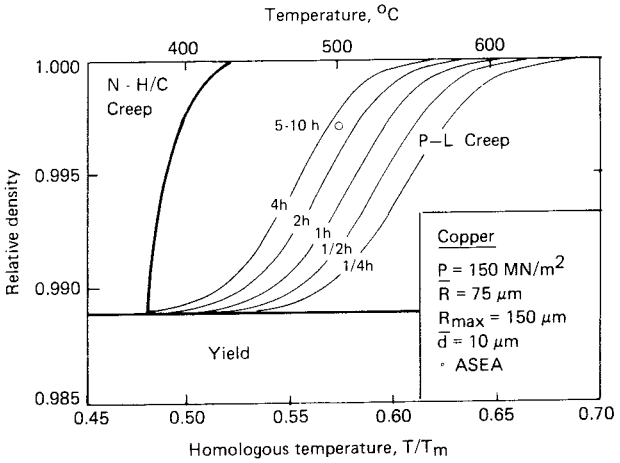


Figure 10-5. Density-temperature diagram for hot isostatic pressing of copper.

10.3 CANISTER MATERIALS

During 1985, the only studies of any importance have been concentrated on copper as canister material.

10.3.1 Copper

As a result of the KBS-3 reviews, some areas for additional studies have been identified, namely:

- Studies of pitting in copper under reducing conditions.
- Inorganic reduction of sulphates to sulphides.
- Achieving better creep data for copper.
- Continued studies of Electron-Beam-welding of copper.
- A better understanding of the Hot Isostatic Pressure-process and the copper material produced through HIPing of copper.

Although work is in progress in all these areas, only the HIPing studies have made substantial progress during 1985.

10.3.2 HIPing of copper

During 1985, the HIPing studies of copper have concerned the modelling of the HIP process /10-9/ as well as metallographical studies of the copper material produced through HIPing /10-10/. Over the last few years a number of investigators have contributed to advance the understanding of the mechanisms operative in the densification during HIPing. Such mechanisms involve diffusional redistribution of matter, plastic flow and power law creep in a generally complex way. One way of simplifying the problem is to construct "HIPing Mechanism Diagrams" (see e.g. /10-10/ and references therein), which identify the dominant mechanisms of densification and which also display the density after a given time at a given temperature and pressure.

Figure 10-5 shows the densification of copper powder at 150 MPa. In the figure are also indicated the results obtained in the halfscale tests performed by ASEA for KBS-3. As can be seen the results are in reasonable agreement with the computations.

Metallographical investigations to assess the powder quality requirements for HIPing copper were also performed. The studies revealed that high-quality powder, treated in inert atmosphere will be necessary to produce copper of a quality comparable to Oxygen Free High Conductivity Copper (OFHC). Furthermore, the studies showed that the material where surface oxides had been reduced using H_2-gas revealed definite signs of hydrogen embrittlement. An alternative method of using CO/CO_2 mixtures for reduction was proposed and will be investigated further.

11 ENGINEERED BARRIERS, DESIGN AND TECHNOLOGY

11.1 GENERAL

The KBS-3 repository concept includes as engineered barriers a copper canister and highly compacted bentonite in deposition holes drilled vertically down in a system of horizontal tunnels at a depth of about 500 m in crystalline bedrock. See /11-1/ for a detailed description of this concept.

Alternative concepts for final disposal have been reviewed by SKB during 1985 as a preparation for setting-up a new R&D-program that will cover also alternatives to the KBS-3 concept.

During 1985 SKB has also closely followed and participated in the studies on the WP-cave-concept sponsored by the National Board for spent Nuclear Fuel /11-2/.

11.2 CLAY BARRIERS

11.2.1 Overview

The effects of a temperature gradient on the water uptake, the swelling and the chemical stability of bentonite have been studied for many years in the buffer mass test in the Stripa mine. This project was finalized during 1985. See further Section 16.2.3.

Two examples of mechanical interaction between a canister and the buffer mass are the settlement of a canister and the shear of a canister in a deposition hole due to rock deformation. Understanding the rheology of the system water/smectite mineral is the basis for the analysis of stress/deformation with time in both cases. The results from earlier testings of creep in highly compacted bentonite were used for a theoretical analysis of canister settlement. In a small-scale model experiment the settlement was measured, see 11.2.2 below.

A test of tectonically induced shear of a canister in a simulated deposition hole has been planned and a pilot test was performed, see 11.2.3 below. In the future the rheological properties of dense smectite clays will be studied in cooperation with the French organization CEA.

Deposition holes in rock may be hydraulically interconnected. If hydraulically conductive fractures can be identified and cut off through sealing it would improve the isolation of the waste considerably. Sealing of fractures in the rock adjacent to plugs in shafts or drifts would also improve isolation. To achieve this aim suitable substances and methods for filling water bearing fractures have to be studied and developed, see 11.2.4 below.

11.2.2 Canister settlement

The KBS 3 concept for isolating highly radioactive reactor waste from the biosphere is based on the use of copper canisters surrounded by dense smectite clay. The canisters exert a vertical pressure on the clay, which leads to settlement, that is almost exclusively caused by shear-induced creep of the clay. The magnitude of this settlement has been studied theoretically as well as experimentally.

The clay is microstructurally non-homogeneous, and a stochastic model of creep, previously developed, should therefore apply. This model yields the often observed creep law, according to which the strain is proportional to log time, and this relation has also been observed in triaxial creep tests from which the creep parameters required for estimating the canister subsidence can be obtained. In a small-scale model experiment with the same contact pressure, 400 kPa, as the real canisters will exert on the clay, (Figures 11-1, 11-2), the settlement was found to comply roughly with this creep (Figure 11-3). The agreement

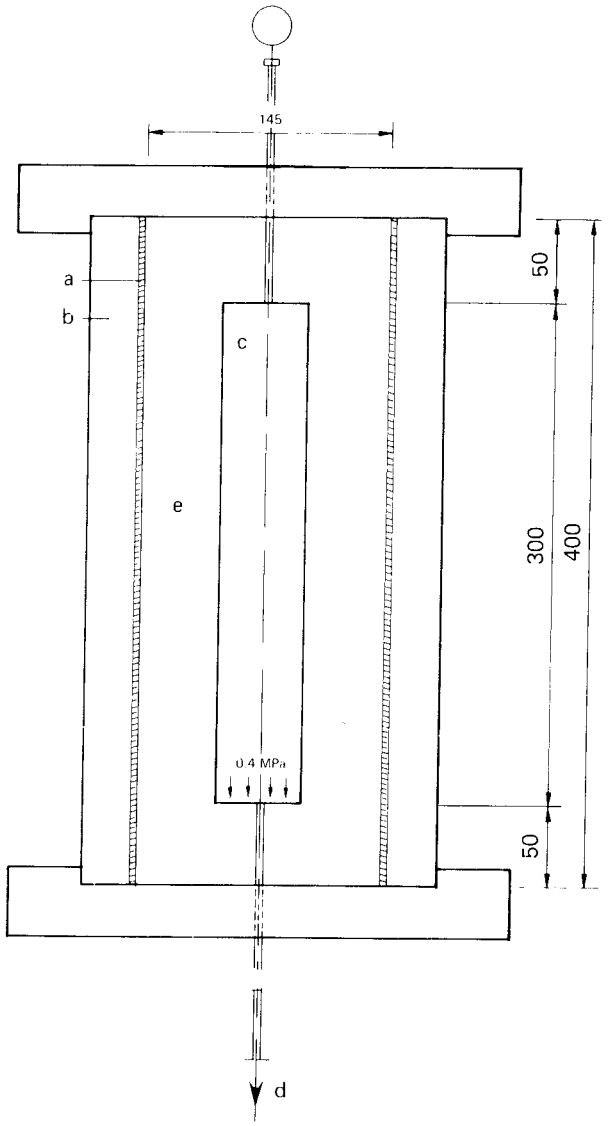


Figure 11-1. Schematic picture of model canister (c) embedded in highly compacted bentonite (e) with a bulk density of about 2.1 t/m³ in a water saturated state. b is a steel container and a filter for water saturation. d is a dead load of 80 kg.

suggests that the model used, and the mode of evaluating the settlement, are relevant.

Increased temperature is expected to speed up the settlement rate but the net displacement of the canisters, which will remain completely enveloped by the clay, will not exceed about 1 centimeter in a million years according to theory. Continued testing at 70°C over a longer period of time is planned for 1986.

11.2.3 Test of tectonically induced shear of a canister in a deposition hole

In this test the shear of a canister and the surrounding compacted bentonite due to tectonically induced rock movements is simulated in the scale 1:10. A copper canister with a diameter of 8 cm and a length of 45 cm is embedded in compacted bentonite. The location of canister and bentonite in a deposition hole is simulat-

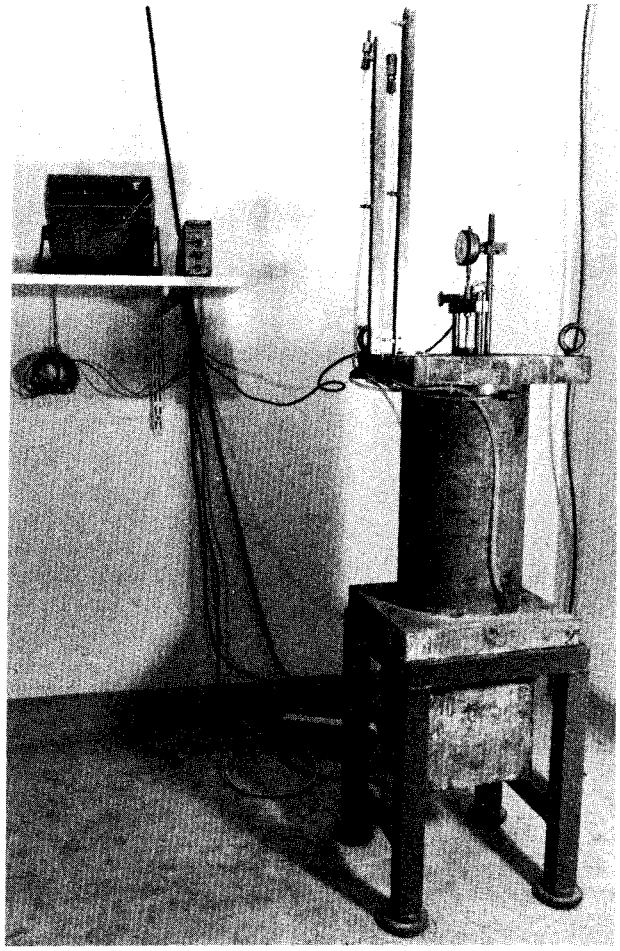


Figure 11-2. Experimental setup in climate chamber. The settlement reading is made by use of an electronic transducer with a nominal accuracy of 10^{-7} m.

ed by a steel cylinder with 3 cm thick walls and an outer diameter of 26 cm. The steel cylinder is equipped with a 60 cm long bronze filter with an inner diameter of 16 cm for the wetting of the clay. The whole device is divided in two halves for the shearing event. (Figure 11-4.) The copper canister is provided with 5 strain gauges and 3 pressure transducers in order to measure the pressure from the bentonite and the strains of the canister during the water uptake phase and during the shearing. The relative displacement of the canister parts as well as the "rock" displacement, rock pressure and shearing force, are also measured. Three tests with different shearing rates will be performed, the fastest being 50 mm/sec.

A pilot test using a compacted sand/bentonite mixture was conducted in November. The first real test was prepared in the beginning of December. Preparation of the first test, with compacted and water saturated bentonite is going on.

11.3.4 Rock sealing

Promising pilot tests have been made in an attempt to attack the wellknown problem of sealing water-bearing rock fractures with an aperture smaller than about 0.5 mm. The research work, which comprises small scale injection tests with clay and cement slurries as

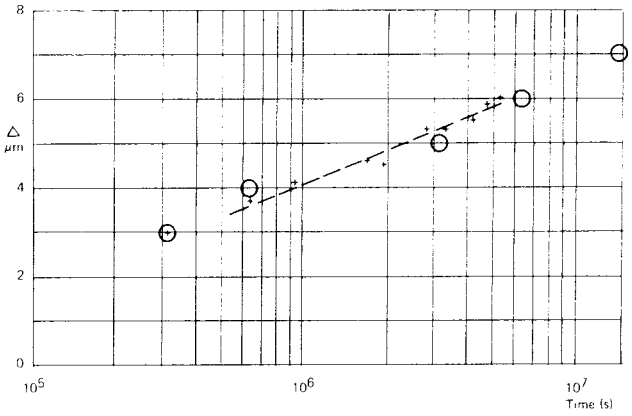


Figure 11-3. Settlement of model canister. Crosses represent recorded settlement while rings are predicted settlement for specific time values.

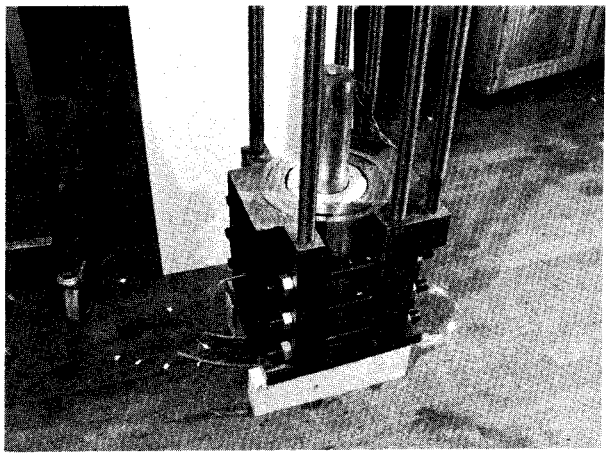


Figure 11-4a. The copper canister and the compacted bentonite placed in the lower part of the "deposition hole".

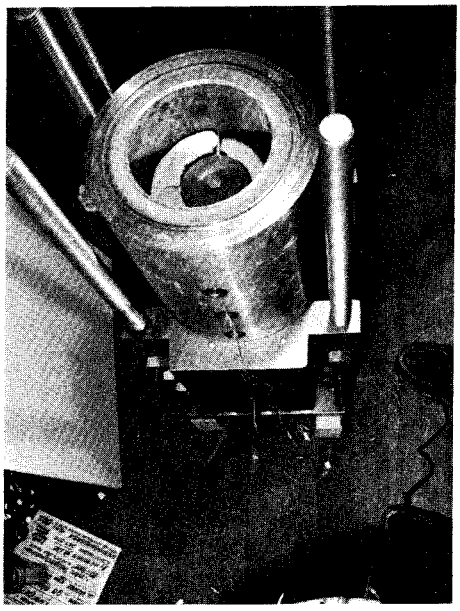


Figure 11-4b. The upper part of the deposition hole is mounted. Some of the cables from the strain gauges and the pressure transducers can be seen.

well as a pilot field test has shown that fractures with an aperture as small as 0.1 mm can be effectively grouted with relatively thick slurries to several decimeters or possibly meters from the injection point.

A survey of potential methods and substances for sealing of rock fractures was also performed. The survey and the preliminary results from the field test still running are reported in SKB technical report 85-17.

Further testing is required to verify the efficiency of the grouting particularly with respect to the erosion resistance and chemical stability of injected materials.

12 CHEMISTRY

12.1 GENERAL

The chemistry program studies cover four major areas:

Groundwater chemistry investigations, including rock mineral studies, to characterize the geochemistry of the undisturbed repository environment and to predict the chemical effect of excavation, presence of canister and backfill material, heat generation etc.

Radionuclide chemistry to assess the behaviour of radionuclides in the near field of the repository and in the undisturbed rock-groundwater environment.

Transport model development to describe the conditions affecting the integrity of the repository and the eventual release and dispersion of radionuclides.

Validation of models for the release and transport of radionuclides by laboratory simulations, in situ tests and natural analogue studies.

12.2 GROUNDWATER CHEMISTRY

12.2.1 Groundwater analysis

The mobile field laboratory, including the downhole equipment for in situ measurements of Eh and pH, was introduced in the later half of 1984. It has been successfully used during 1985 to finish the chemical investigations at the Klipperås site. Numerous test-runs have also been performed at Fjällveden - a former investigation site.

The failure rate of groundwater sampling and analysis has gone down considerably after the introduction of the mobile field laboratory. The main reasons for that is:

- Tagging of drilling water followed by direct field analyses of the residues in the groundwater samples.
- In field analyses of main components and redox sensitive trace components of the groundwater.
- Longer packer sleeves and carefull pumping to avoid infiltration of water from outside the isolated sampling section.
- Downhole measurements of Eh to avoid the influence from traces of atmospheric oxygen.

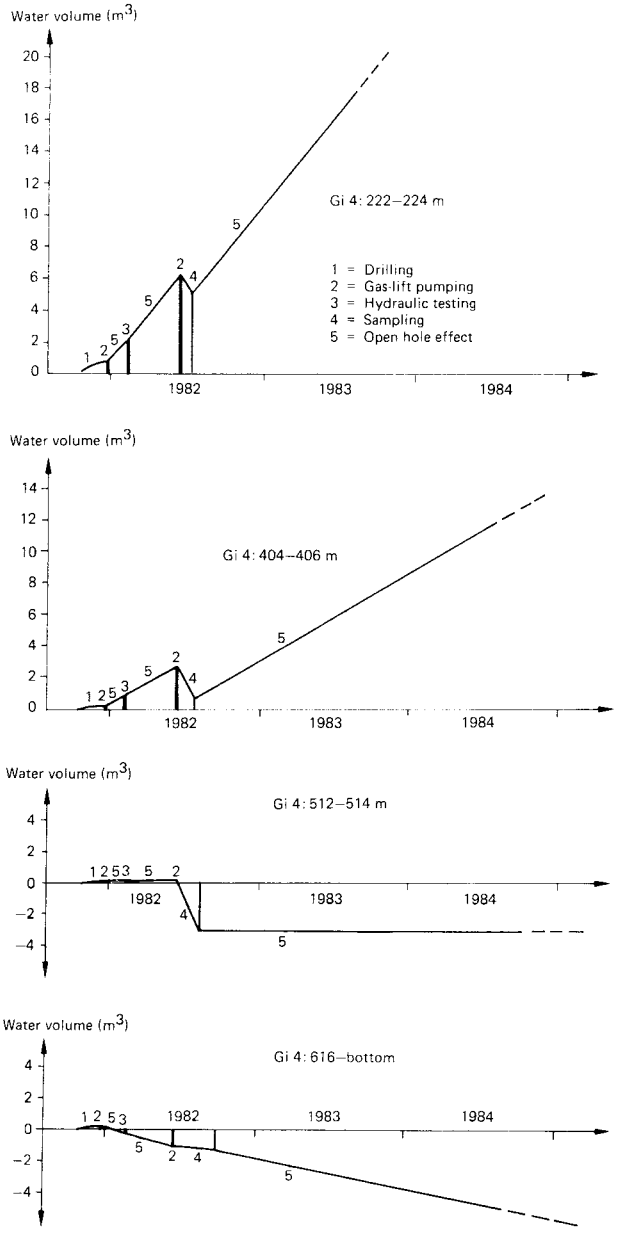


Figure 12-1. The variation in water budget in different groundwater sampling sections in the borehole Gideå 4 due to 1) drilling, 2) gas-lift pumping, 3) hydraulic testing, 4) sampling and 5) open hole effect. Increasing values means inflow to the rock from the borehole. The calculations are based on measurements of hydraulic conductivity.

Hydrochemistry data from the site investigation program have been reexamined in the light of detailed hydrological measurements and models. Only sampling and analyses done with the older field equipment have been considered, and the study comprises investigations in the areas Fjällveden, Gideå, Svartboberget, Kamlunge and parts of Klipperås (SKB TR 85-11). The hydrogeological conditions have a strong influence on the sample quality, see Figure 12-1. Most sensitive are the concentrations of natural radioactive isotopes originating from the atmosphere such as tritium and carbon-14. Easily influenced are also trace

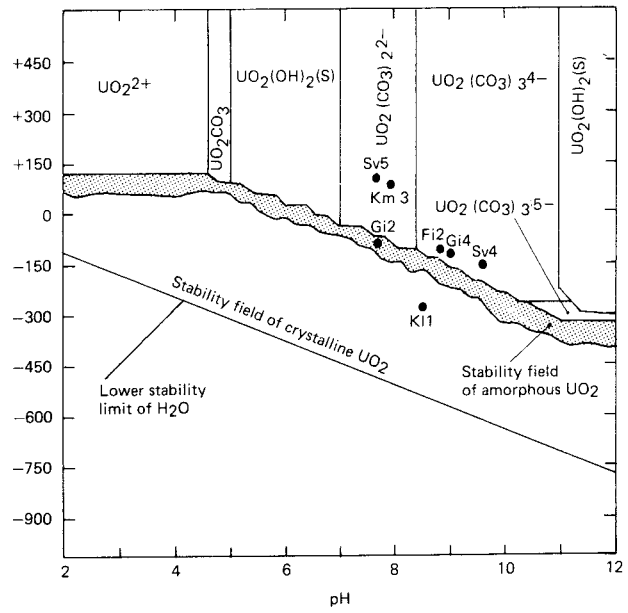


Figure 12-2. Eh-pH diagram of the uranium-carbonate system with measured values from the investigation sites Fjällveden (Fj 2), Gideå (Gi 2, 4), Svartboberget (Sv 4, 5), Kamlunge (Km 3) and Klipperås (Kl 1). See also Table 2-1. The ground surface equipment have been used for the Eh- and pH-measurements.

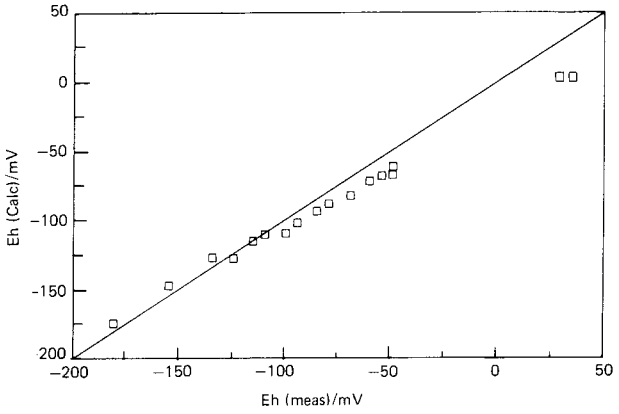


Figure 12-3. Eh calculated for the sulphide/sulphur system compared to Eh measured with a platinum electrode in the ground surface equipment. The water is pumped up to the ground surface.

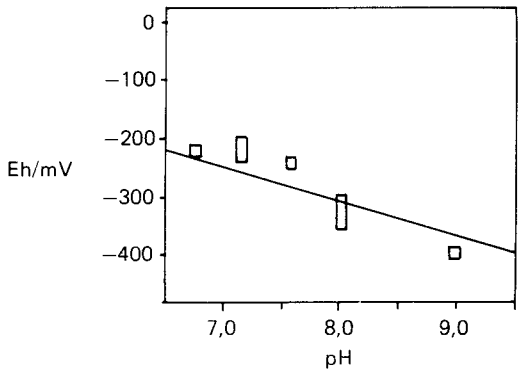


Figure 12-4. Eh and pH values of groundwater measured in situ with the downhole equipment. The bars indicate the maximum variation of the Eh values measured simultaneously with platinum, gold and glassy carbon electrodes. The line corresponds to the redox equilibrium in the magnetite/hematite system.

concentrations of redox sensitive groundwater components such as iron(II) ions, sulphide and uranium. Reexamined uranium data have been put together and compared to theoretical predictions of uranium chemistry, see Table 12-1 and Figure 12-2. The report SKB TR 85-11 will be used to guide further improvements of sampling equipment and data evaluation.

Table 12-1. Measured uranium concentrations, pH and Eh in groundwater from the SKB test-sites, Fjällveden (Fj 2), Gideå (Gi 2, 4), Svartboberget (Sv 4, 5), Kamlunge (Km 3) and Klipperås (Kl 1). The ground surface equipment has been used for the Eh-, pH-measurements.

Borehole	Level	pH	U ppb	Eh mV
Fj 2	605	8.9	< 0.2	− 115
Gi 2	178	7.7	0.23	− 100
Gi 4	222	9.0	0.98	− 120
Sv 4	376	9.6	0.22	− 140
Sv 5	160	7.7	44.5	+ 120
Km 3	123	7.9	24.3	+ 100
Kl 1	403	8.4	0.68	− 300

12.2.2 Redox measurements

The redox properties of groundwater are determined by trace concentrations of redox active species such as iron(II) and sulphide ions. A good correlation has been found between redox potentials measured with inert electrodes and redox potentials calculated with the geochemical code EQ3/6 assuming sulphide-sulphur as the active redox pair, see Figure 12-3.

These measurements were made with the ground surface equipment to which the water is pumped from the sampling section. Trace amounts of oxygen is believed to have affected the system which would explain why in situ measured redox potentials, using the new downhole equipment, are considerably lower, see Figure 12-4.

The redox buffering capacity at depth in granitic rock is of course not founded in the trace amounts of dissolved redox active species but rather in the rock itself.

Kinetic studies of the reduction rate and capacity in a simulated rockgroundwater system in the laboratory are therefore important for the overall redox investigation program /12-1/.

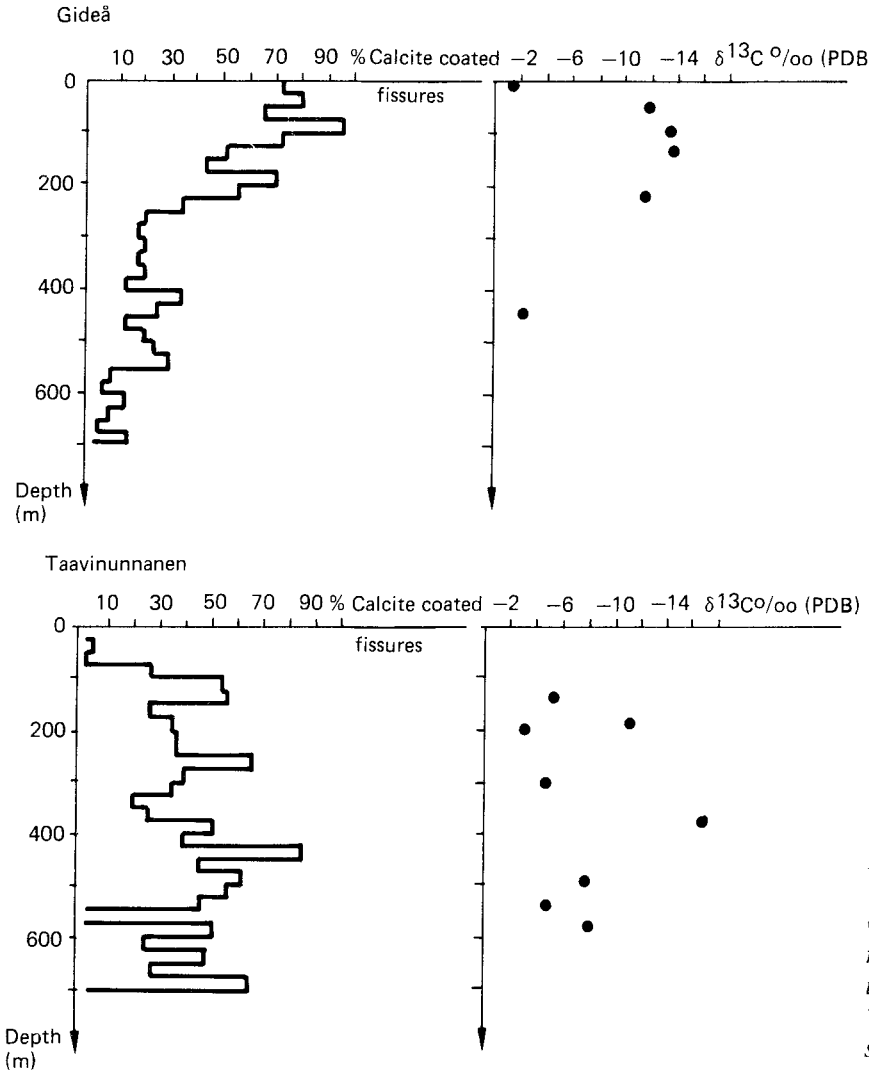


Figure 12-5. Frequency and carbon-13 content of calcites in open fissures. The samples have been taken from Gideå and Taavinunnanen. Both represent recharge areas but there is a strong tendency of inflow in Taavinunnanen in contrast to more stagnant conditions in Gideå.

12.2.3 Fracture minerals and isotopes

Calcites may initially be dissolved at the recharge and later precipitated as the chemistry of the groundwater develops along the flow paths. Hydraulic conditions are therefore reflected by the character, frequency and isotopic composition of the calcites, see Figure 12-5.

The content of atmosphere generated radioisotopes in the groundwater should at least in principle yield the time of isolation. The carbon-14 content of dissolved carbonates are widly used for that purpose. However, carbonates from "old" calcites may initially be released to the groundwater thus lowering the $^{14}C/^{12}C$ ratio. This and other disturbing factors are difficult to compensate for /12-2/.

The use of accelerator technique has made it possible to analyse the carbon-14 content of dissolved organic material. This may be less affected by exchange with the minerals. These accelerator analyses are also being tried on fracture filling calcites.

12.2.4 Geochemical calculations

A first attempt have been made to combine thermodynamic and kinetic data to calculate the effect of heat on the minerals in the near field as a function of time. A decrease in porosity of 10-20% is projected when 100°C and 100,000 years are used as input values /12-3/. Further developments of this model are being considered.

The chemical evolution of sodium bentonite in contact with two different kinds of granitic groundwater - normal and slightly saline - has been calculated at 25°C and 100°C, including mass transfer in the model. (SKB TR 85-10). Only a limited degradation of the bentonite is foreseen. The effect is even less important in the saline water. In particular, no evidence for an evolution to an illite type of clay was detected.

12.3 RADIONUCLIDE CHEMISTRY

12.3.1 Solubility and speciation

Basic thermodynamic constants, describing the solubility, inorganic complex formation and redox properties of lanthanides and actinides in carbonate containing groundwater; are continuously measured /12-4,5,6/.

An important part of this work is done in cooperation with the French organization CEA. The chemistry of the actinides neptunium and plutonium are being investigated within that frame of cooperation /12-7/.

Solid solutions of actinides like americium, plutonium and neptunium in uranium are expected to lower considerably their solubility. This will retard the release of these actinides from spent fuel and also lead to a coprecipitation with uranium if e.g. dissolved uranium is precipitated due to reduction. This phenomena has been quantified by experiments with uranium and lanthanum, using lanthanum as a chemical analogue to plutonium /12-8/.

Basic thermodynamic constants from this program will be introduced into the OECD-NEA organized compilation of a chemical data base for important radionuclides and minerals. An internationally accepted and well documented data base in this field will be of great value.

12.3.2 Colloides, organic complexes and microbes

The formation of colloides, consisting of americium adsorbed on quartz and montmorillonite particles have been studied in batch and column experiments /12-9/.

Organic material have been enriched from large amounts of groundwater collected from 300-400 m depth in Fjällveden /12-10/. The analyses show that the humic content is dominated by relatively low molecular weight fulvic acids. Up to gram quantities of purified fulvic acid samples have been used for a potentiometric determination of the complex forming properties (SKB TR 85-07). A chemical model for the formation of fulvic acid complexes in groundwater is being developed.

A preliminary investigation has been carried out on the importance of microbes for the migration of radionuclides in the geosphere. Further investigations have been recommended.

12.3.3 Sorption and diffusion

The reduction-sorption experiments with technetium, neptunium and uranium on rock samples have been continued. Preliminary results indicate a slow reduction.

Sorption coefficients (Kd-values) are generally used to model the retention of radionuclides, transported by flowing water in rock fractures or diffusion in the porewater of the rock matrix and backfill material. A lack of a more fundamental understanding and the failure to explain certain observations such as cesium diffusion in bentonite clay and rock samples, have been pointed out. The possibility to use surface complexation theory or similar approaches are therefore being investigated.

A large number of experimental investigations of radionuclide diffusion in rock samples have been reported (SKB TR 85-03, 05 and 15). Different experimental techniques have been used, and especially the influence of rock pressure has been tested in an equipment designed for this purpose, see Figure 12-6.

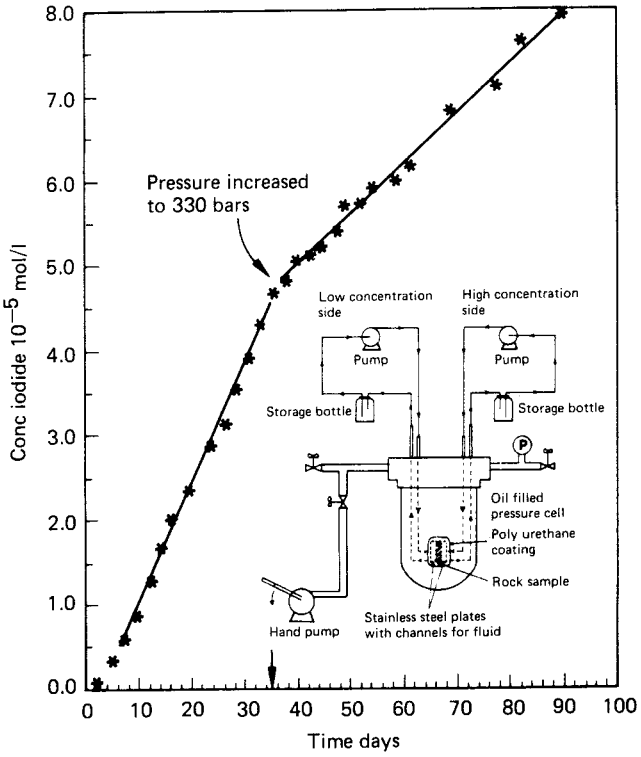


Figure 12-6. Iodide diffusion through a biotite gneiss sample from the investigation site Svartboberget. The experiment was started at atmospheric pressure which was increased to 330 bar after 35 days.

Diffusion of radionuclides into the stagnant water of the open rock pores is an important retention mechanism. A considerable amount of experimental evidence has now been accumulated on the variability and stability of the transport properties of the micropore system /12-11/.

12.3.4 Radiolysis

A theoretical model is used to calculate the upper limit of radiolysis of water by exposure to radioactive material. This model is being tested on a variety of evaluated examples /12-12/.

Experiments have also been carried out to test the radiolysis model. Different sources of radiation in combination with wet bentonite clay have been tested, see Figure 12-7.

12.3.5 Concrete

The chemistry in concrete for radionuclides have been studied and part of this work has been reported, KBS TR 84-15 and /12-13/. The primary aim of these investigations have been to provide data for the safety assessment of low and medium level waste disposal. However, concrete may possibly also be used for the construction of a high level waste repository and it has

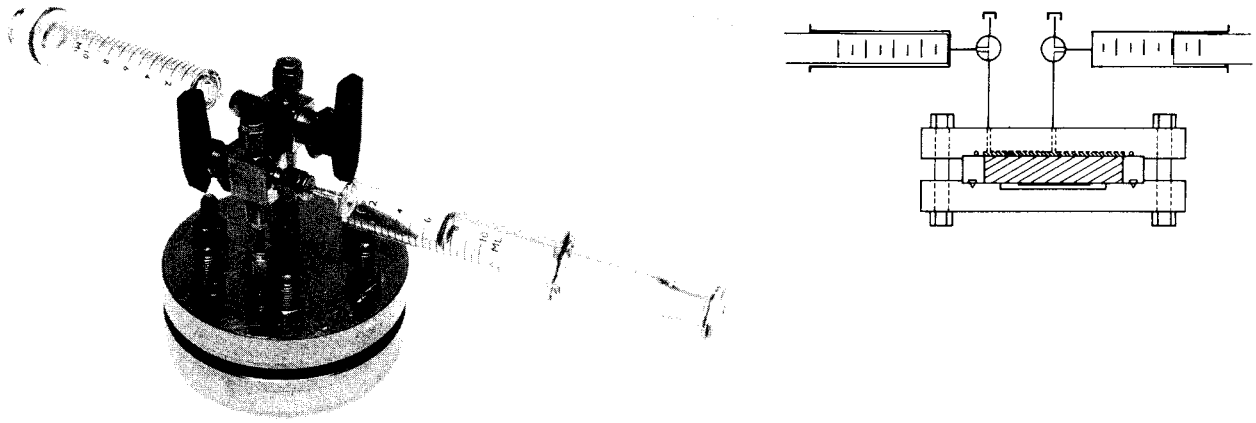


Figure 12-7. Equipment for measuring the hydrogen production in alfa irradiated compacted water saturated bentonite (2.1 g/cm³). The radiation source is ^{241}Am with an active surface diameter of 25 mm. The nominal activity is 30 MBq.

in fact even been suggested as an alternative backfill material /12-14,15/. An increased interest in this field is foreseen.

12.4 CHEMICAL TRANSPORT MODELS

Models are being developed for the transport of radionuclides with flowing water in the fracture zones, SKB TR 85-14 and /12-15/. A large part of the water flow is forseen to occur in the fracture zones and the retention of radionuclides in these zones has not been taken credit for in previous safety assessments.

The distribution of individual fractures and connections between them in the bulk rock or fracture zones are assumed to cause a small part of the flow to be relatively rapid. This effect, referred to as "channeling" may be important for the dispersion of radionuclides. A theoretical treatment of this problem is given in the report SKB TR 85-13. The combined effect of channeling and rock matrix diffusion has also been evaluated /12-16/.

Models for the transport of radionuclides in fractured rock are usually treating the chemistry in a much simplified way. Only one component at a time is treated and a sorption coefficient (K_d) is used to describe the interaction with the rock. A more advanced model would be more relevant, especially in the near field of a repository where larger concentrations of radionuclides are possible and the transport of numerous inactive species plays an important role. Such a model would imply coupling between a geochemical and a hydrological model. The code CHEMTRN, developed at Lawrence Berkeley Laboratories, is being tested for that purpose.

12.5 VALIDATION OF TRANSPORT MODELS

12.5.1 Laboratory experiments

Natural fractures are overcored and used for hydrodynamic flow tests and radionuclide migration experiments. The results are analysed with transport models, taking into account advection, diffusion into the rock matrix, sorption onto the rock surface and flow dispersion (KBS TR 84-04).

A setup for radionuclide migration experiments under reducing conditions is being constructed.

12.5.2 In situ tests

In situ experiments with sorbing and non-sorbing tracers in flowing water are being carried out in the Stripa mine as a part of the international OECD-NEA project (see Chapter 16). Results from recent tests in Stripa and previous tests in other places in Sweden have been summerized /12-17/.

Since 1982, a series of in situ experiments have been going on in Stripa to measure the diffusion properties of the interconnected micropore system in an undisturbed rock mass. Non-sorbing tracers are continuously injected at a slight overpressure from a 20 mm borehole well away from the disturbed zone around the tunnel. The borehole is later overcored and the surrounding rock mass also sampled by core drilling. Two tests have been finished, analyzed and reported (KBS TR 82-08 and 83-39).

The injections of the third and last test have been going on since 1982. This is by far the longest injection period. The last test place has now been sampled by core drilling and the laboratory work has started.

12.5.3 Natural analogue studies

The Oklo reactor

Parts of the Oklo uranium mineralization have been active as natural fission reactors two billion ($2 \cdot 10^9$) years ago. The nuclear products were formed within the grains of the mineral uraninite. Uraninite has been remarkably stable during the extreme length of time. More than 90% of the "fuel" has remained in the spatial configuration it had during criticallity. Actinides and rare earth elements have largely remained in place whereas technetium, alkali and alkaline earth elements were not effectively contained. However,

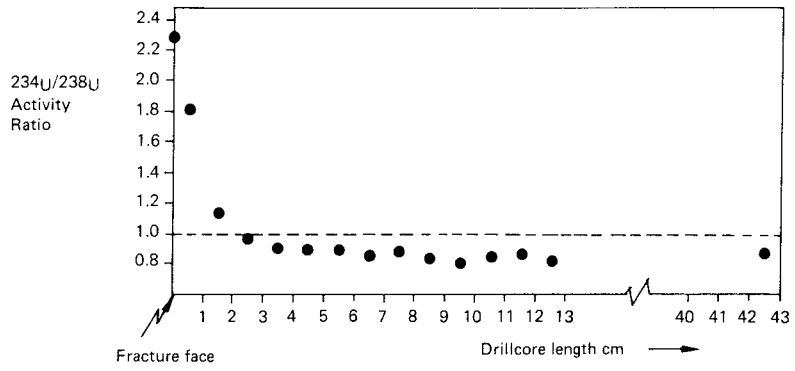


Figure 12-8. The uranium isotope activity ratio $^{234}U/^{235}U$ is a drillcore from Kråkemåla (granite). Samples have been taken on the face of a water conducting fracture intersecting the drillcore and from sections at increasing distance from the fracture.

many of the nuclear products which were removed from their site of production have been contained in the surrounding sandstone. This and other information has been summarized in a report (SKB TR 85-04).

Poços de Caldas
A continuation of the investigations of the large thorium mineralization in Morro do Ferro, Poços de Caldas, is foreseen - supplemented by the investigation of a uranium mine situated in the same area.

Uranium mobility
The mobility of uranium and related elements are being studied in drillcores taken from one granite location in Sweden (Kråkemåla) and two sites (granite and gneiss) in Switzerland (Grimsel and Böttstein). The cores are chosen so that they are intersected with water conducting fractures.

One important conclusion from the study of the Kråkemåla sample is that natural radionuclides have accumulated along the fracture and migrated into the granite to a distance of some 3 cm, see also Figure 12-8. This investigation is done in cooperation with the Swiss organization NAGRA. Part of the results have been presented, KBS TR 84-18 and /12-18/.

An inventory of Swedish uranium mineralizations have been started with the aim to find suitable formations for future natural analogue studies.

13 GEOSCIENCE

The activities within the field of geoscience are divided into two main parts:

- Site selection studies, i.e. investigation of the Swedish bedrock in order to find sites suitable for final disposal of spent nuclear fuel.
- Research and development.

13.1 SITE CHARACTERIZATION STUDIES

The overall time-schedule for the site selection studies is shown in Figure 13-1. In total around 10 sites will be investigated by surface and borehole observations following a defined standard program. Two or three of those sites will be selected for detailed studies around year 1990 and the recommendation for a specific site is expected to be given around year 2000.

The major rock types studied so far are granite, gneiss and to some extent gabbro. Further studies of gabbroic rock have been initiated.

Figure 13-2 shows the location of sites investigated and below a short summary is given of results obtained during 1985.

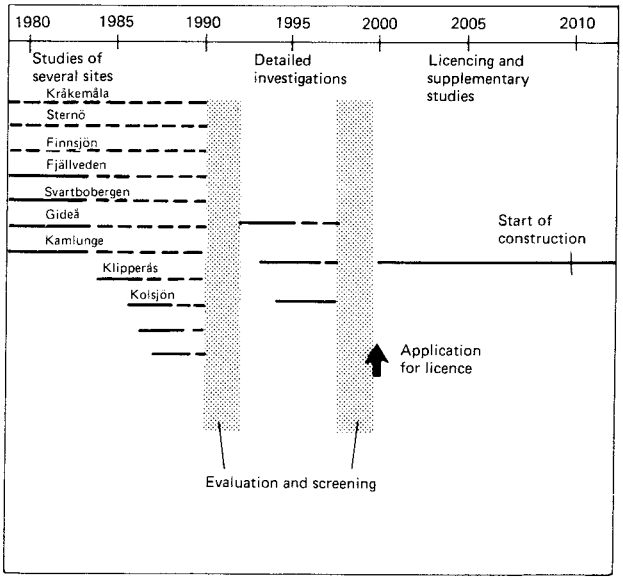


Figure 13-1. Time-schedule for site selection studies.

13.1.1 Klipperås

The site Klipperås is located in the south-eastern part of Sweden, see Figure 13-2. The site is characterized by a very flat topography and a widespread thin soil cover made the surface geological interpretation uncertain. The few existing outcrops were mapped as an homogeneous, red mediumgrained granite.

13.1.2 Gabbro studies

Available geologic material has been studied to establish the advantages and disadvantages of siting the repository to a gabbroitic rock mass. Further an inventory of potential sites has been performed in which in total about 400 areas were localized. Out of these, 35 areas were studied in the field and within 4 of the areas gravimetric measurements were performed in order to determine the thickness of the gabbroitic rock mass. The most promising area was found to be Kolsjön 7 km E of Almunge, see Figure 13-2.

The Kolsjö gabbro covers an area of about 5 km^2. The topography is flat and the area is covered by a thin soil layer. The rock can be studied in a number of outcrops and cuts. The gravimetric measurements indicated that the thickness of the gabbro massive is more than 1,000 m. In order to verify this, drilling of a coredrilled hole in the central part of the massive has been initiated. The hole is planned to be drilled to a depth of 1,000 m. The drilling has, however, been interrupted and postponed due to protests from local public groups.

Results from previous studies at the Taavinunnanen gabbro massif has been reported in a SKB technical report (SKB TR 85-02).

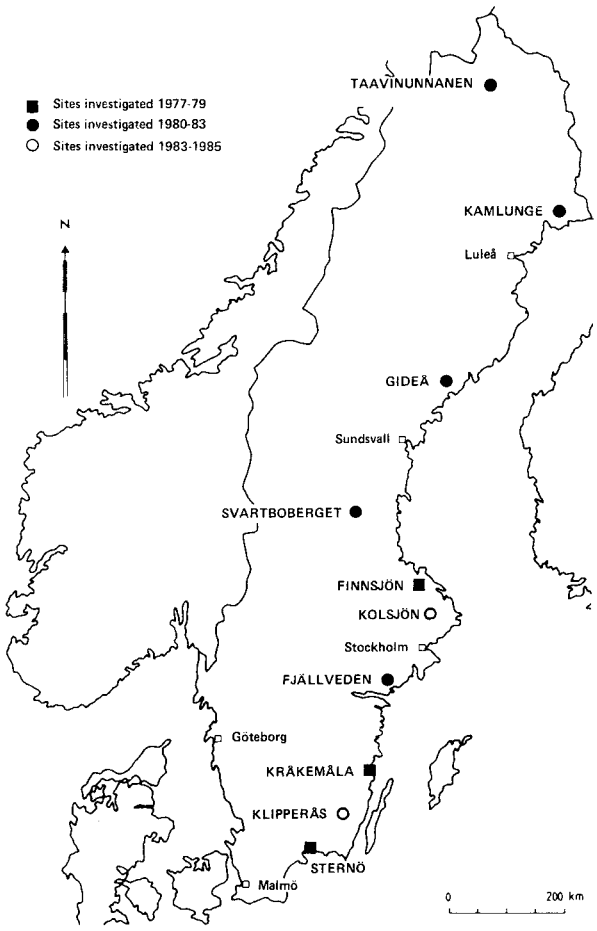


Figure 13-2. Location of study sites.

13.2 RESEARCH AND DEVELOPMENT

13.2.1 Geology

Fracture zone study

The groundwater flow and the transportation of radionuclides in existing fracture zones are of crucial importance in the safety assessment. In order to allow a better modelling of water movements and nuclide migration in fracture zones a 4-year program has been initiated where the following characteristics will be investigated,

- geological characteristics, i.a. tectonic evolution, structure and age relationships,
- hydrogeological characteristics, including migration properties,
- geochemical characteristics, i.a. hydrogeochemistry, fracture mineralogy, redox capacity and the interaction of water and rock,
- rock mechanical characteristics including deformation properties, rock stresses and the influence of rock stresses on the hydraulic properties.

The studies have been concentrated to a zone in the Finnsjö area, see Figure 13-2. A relatively complicated fracture pattern has been established by means of coredrilled holes and interference testing. Thus a subhorizontal zone is found to have a dominating importance for hydrology of the upper part of the rock and the steep zone, which the investigations initially were aimed at is less important. Chemical sampling and geophysical measurements in the drillholes show that the subhorizontal zone formes a border between fresh and saline water. As part of the testing programme requires that the zone can be traced and uncovered at the surface and this might be difficult in the Finnsjö area preliminary studies have been initiated at Ävrö in the Simpevarp area. The studies within this area have comprised geophysical surface measurements and geologic surface mapping as well as radar measurements in two previously drilled boreholes. The results will be the basis for further decisions on studies of the Ävrö fracture zone.

Bedrock stability

A 3-year project to increase the knowledge on the mechanical behaviour of a rockmass exposed to stress changes has been initiated. Planning of research activities in the fields of structural geology, seismology and rock mechanics has been carried out. Monitoring the Finnsjö area, which is considered to be low-active from seismicity point of view, with a mobile seismograph net has been performed in order to gain experience on suitable layout and measurement performance.

An aftershock survey, comprising three stations, was conducted in southern Sweden after the Halmstad earthquake 1985-06-15.

The elastic and mechanical properties for two rock types from the Gideå study sites have been determined and the results are reported in SKB TR 85-06.

13.2.2 Geophysics

Radar measurements

Further development of the radar equipment to make it possible to use the down-hole unit in 56 mm holes down to a depth of 1,000 m has been performed. The complete radar unit has been redesigned to meet the requirements of severe field conditions and the interpretation technique has continuously been improved. Measurements have been performed in the fracture zone project within the Finnsjö and Ävrö sites. The equipment has also been tested in the Swiss program with promising results. Penetrations up to 160 m have been achieved under favourable conditions.

Scanning borehole TV-camera

Development of a scanning borehole TV-camera designed to fit boreholes with a diameter of down to 56 mm has been initiated. The equipment will make it possible to determine the orientation of fractures intersecting the boreholes.

13.2.3 Hydrogeology

Tracer tests

Tracer tests over short distances (1-5 m) have been carried out at the Stripa mine, SKB TR 85-12. Pulse tests have been evaluated according to a method which makes it possible to get a three dimensional picture of the hydraulic conductivity of the rock mass. Testing has also been performed injecting a macromolecule (Dextran) in order to establish the importance of diffusion and verify earlier tests with non-sorbing tracers and the above mentioned pulse tests.

The natural flow can be measured in boreholes within a section or a specific fracture with a dilution probe. The dilution of a tracer in a borehole section is measured without disturbing the natural water flow in the tested section. See Figure 13-3. By combining the results from measurements in different boreholes the mean flow values can be calculated. A further development of this probe will hopefully also give the direction of the measured flow.

Hydraulic modelling

SKB participates in a project aiming at modelling the effects on the hydrogeological regime around the shaft sunk to the Underground Research Laboratory (URL) in Canada. Measurements performed in drillholes around the shaft make it possible to validate the model calculations.

SKB also participates in the international HYDROCOIN-project with the GWHRT/HYPAC-model, /13-1/, /13-2/ developed at the Royal Institute of Technology. The performance of this model has been very satisfactory when applied to the benchmark cases set up within HYDROCOIN. Studies are also underway on the use of statistical methods in hydromodelling /13-3/.

The results from a large number of single-hole packer tests in crystalline rock from three test sites have been analysed statistically and a comparison between steady state and transient analysis of the same test data has been performed (SKB TR 85-19).

Improvement of equipment

The multihose equipment for hydraulic testing utilizing trancient injection method has been modified and is now working properly. To facilitate measurements of the conductivity in low-conductive zones the steel mandrel outfit has been modified. Further the piezometric equipment has been improved by changing the valves to a more durable type.

13.2.4 Hydrogeochemistry

The specially designed field laboratory for chemical analyses of groundwater has been utilized within the Klipperås, Finnsjön and Fjällveden sites. The results of the measurements have been accurate and reproducable.

Development of a gas sampler has been performed and the unit will be incorporated in the field laboratory early 1986.

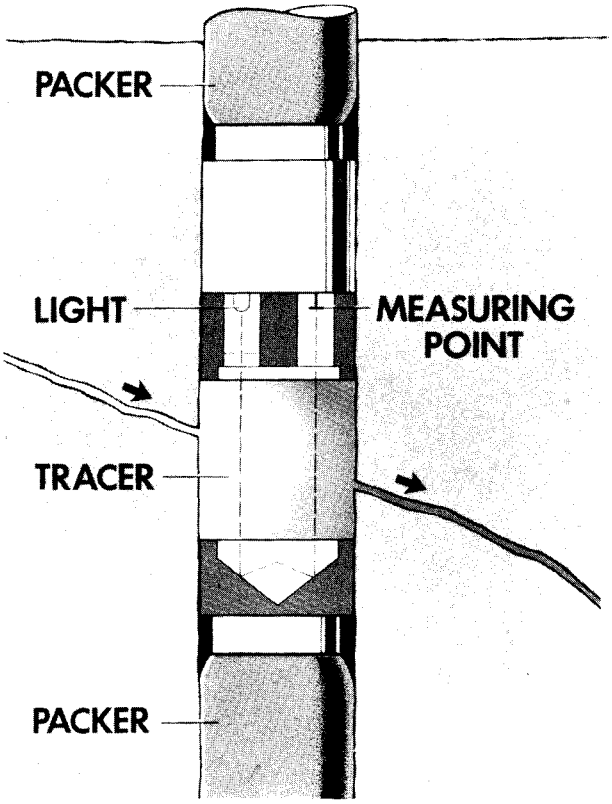


Figure 13-3. Dilution probe for measurement of groundwater flow.

14 THE BIOSPHERE

14.1 BIOSPHERE CHARACTERIZATION AND NATURAL RADIOACTIVITY

Parallel to the geological site investigation a characterization of the biosphere in general and of soil and surface waters with regard to natural radioactivity is made in the investigation areas.

During 1985 two investigations were completed, one at Bjulebo, the other at Klipperås, both situated in the south-east part of Sweden.

In Klipperås a complete geological site investigation has been performed. This was also intended for Bjulebo, but a new law reserved this region for recreational purposes, and no drillings were made. Since Bjulebo is a typical Swedish coastal area, however, the surface investigations were completed.

The two recipient areas are completely different. In Bjulebo two types of groundwater recipients are identified: a brackish bay and a lake. Klipperås on the other hand is an inland site where the recipients are bogs. One of these is a former lake situated above a marked fracture zone in the bedrock.

Gamma ray surveys, covering representative soil types, gave average exposure rate values of about 18 μR/h for both sites. This corresponds to a radiation dose of about 1.5 mSv/y.

Concentrations of Th and U were determined in rock, soil and plant samples and activities of Ra-226, Ra-228, Th-228, Cs-137 and K-40 in soil and plant samples. Average concentrations in Klipperås samples are for granite (dominating rock) 20.7 ppm Th and 6.6 ppm U, for soil (upper zone) 5.6 ppm Th and 2.9 ppm U and for peat 1.8 ppm Th and 2.4 ppm U (dry weight). Fairly high concentrations were observed in some organic soil samples, 11.5 ppm Th and 13.1 ppm U. The nuclides in the U and Th decay chains are usually in disequilibrium, indicating different migration patterns for the radium, uranium and thorium isotopes. A much higher root uptake of radium isotopes as compared to uranium and thorium isotopes was observed.

Figure 14-1. Sampling of water and sediments from a lake.

The water quality and the content of U, Ra-226 and Rn-222 in ground- and surface water samples were determined. The Ra-226/U-238 activity ratio is in average 0.1 for the Bjulebo and 3.1 for the Klipperås water samples, i.e. the uranium content is roughly the same whereas the Ra-226 content is very low in the Bjulebo water samples.

Both areas are reported in SKB TR 85-09.

14.2 NATURAL AGEING IN GROUNDWATER RECIPIENTS

The studies of the change in physical and chemical characteristics of lakes and Baltic bays with time have continued during 1985.

Sampling of water and sediments in lakes, streams and a bay has been performed in a study area around the Studsvik research laboratory. Data has been collected on water flow, suspended matter, macro constituents in the water, pH, conductivity, sedimentation rate, trace metals etc.

The properties of sediments down to 150 cm depth are investigated with regard to porewater chemistry, redox conditions and trace metal partitioning.

An in situ study of the diffusion of radionuclides in sediment cores is in progress and the first results are expected in April/May -86. Laboratory measurements of sorption and trace radionuclide complexation are also performed in this study. During July 1985 a vegetation mapping of Sibbo- and Trobbo-fjärden was performed.

The field sampling and laboratory study phase will be finished in -86 and a third phase will commence. This will include a modelling of how the growth and changes in the sediments will influence the behaviour of radionuclides released from a repository, prediction of the behaviour of "immobilized" radionuclides when the lake sediments turn into an agriculture area, and dose calculations.

14.3 FUTURE PLANNING

Biosphere investigations in different parts of the world show a substantial variability in the transfer of

radionuclides from the groundwater to man. The variability can be due to differences in

- chemical composition of the geosphere influencing the groundwater chemistry,
- climatic differences affecting the availability of groundwater and the development of the ecological network of pathways for the radionuclides,
- types of groundwater recipients and their state of natural development affecting what pathways will dominate the nuclide transfer to man.

For the coming few years the biosphere investigations within SKB will continue to focus on the mapping of the variability due to the natural development of the recipients. Some new investigations will be initiated to evaluate the effect of the geochemistry on local groundwater outflow areas in lake sediments peat, or soil.

15 SAFETY EVALUATIONS

During 1985 the work in the area of safety and performance assessment has continued along the lines layed down after the finalization of the KBS-3 study. That means a shift from conservative feasability studies towards the development of performance assessment tools satisfying a set of different needs for:

- making R&D-program priorities
- design optimisation
- site screening and ranking
- safety assessment for licensing purposes.

The long time perspectives connected with the safety assessments of repositories for high level waste require that special consideration is given to questions concerning international consensus in evaluation methodology and acceptanced criteria. SKB has taken an active part in the IAEA and OECD/NEA efforts in this field.

15.1 MODELLING WORK

An important ingredient in the SKB performance assessment plan is the continued development and validation of models that is taking place at different levels:

- detailed research-related modelling of various processes and phenomena in geochemistry, fuel matrix dissolution, radiolysis etc. and their interaction (scientific models),
- development and coupling of simpler scientific models into nearfield, geosphere and biosphere models for radionuclide transport calculations (assessment models),
- development of a computer code for use in uncertainty and sensitivity analyses and in probabilistic* safety assessments (probabilistic systems analysis models).

The basic research, the collection of data and the detailed modelling of processes and phenomena, areas which are covered in other chapters of this report, constitute the scientific basis for the rest of the assessment and modelling work.

The scientific background will continue to be emphasised by SKB. Increased attention will be focused on the quality of the computer programming, on the administrative control and the testing of computer codes and on other measures for enhancing the confidence in the model predictions such as verification and validation (cf Chapter 12 and 13).

SKB is also supporting work on the modelling of coupled processes such as hydrology-geochemistry and rock mechanics-hydrology.

Codes (some of which can also be regarded as scientific codes) that have been used in the KBS work or will be used in the future is given in Table 15-1.

Table 15–1. Codes that have been or will be used in SKB performance assessments.

Code	Use	Features
HYPAC/ GWHRT	Geohydrology	3-D, homogeneous medium, double porosity Forced convection Various boundary conditions Fintite elements
QEQAL	Near-field migration	Design-specific Diffusion through clay barrier to cracks in rock
LCHCAL	Near-field migration	Chain decay Solubility limitations
NUCDIF	Geosphere migration	1-D matrix diffusion Single nuclide Decaying band concentration boundary condition Semi-analytical
TRUCHN (TRUMP)	Near-field and far-field modelling	General 1-D, 2-D or 3-D Chain decay Arbitrary boundary condition Integrated finite differences
BIOPATH	Biosphere modelling and dose calculations	Compartment theory

* Propabilistic in the sense that inputs can be entered as probability distributions.

15.2 PROBABILISTIC SYSTEMS ANALYSIS

15.2.1 The PROPER code

A new performance assessment tool is being developed by SKB, the PROPER computer code. Important aspects are the possibilities of

- using probability distributions for the input parameters to obtain the related uncertainty in the computed results,
- doing sensitivity analysis to find out the important parameters with respect to the results and variability,
- having a general and modularized system for the fast and flexible handling and linking of a library of submodels for radionuclide transport calculations (assessment models).

PROPER is inspired by and to some extent based on the ideas of the SYVAC code of the Atomic Energy of Canada Ltd. Like SYVAC, it uses a Monte Carlo technique to find the variability of the results. This technique requires the use of simplified submodels for the radionuclide transport. During 1985 work on the PROPER code has been concentrated on the executive program and submodels.

A programming standard has been developed for PROPER to facilitate the documenting and maintenance of the code. The standard defines a subset of FORTRAN77 and includes recommendations for structured top-down programming.

15.2.2 The executive program

The core of PROPER is the executive program, containing systems for the linking of submodels (i.e. subroutines or separate programs) and the handling of the communication between them, for sampling input data and for collecting statistics from calculations, see Figure 15-1. The monitor part of the executive program allows two kinds of input to the submodels: parameters and time series, and one kind of output: time series, cf Figure 15-2. The user can make his choice from the library of submodels and link them any way he or she likes with the restriction that no feedback is allowed between submodels.

The post-processor is a separate program that is used for the statistical processing of the results.

15.2.3 Submodels

The detailed scientific models are much too complicated to be used as submodels for PROPER. Rather simplified submodels have to be used. The first submodels are simplified versions of models used in the KBS-3 assessment. They are based on a generic site, KBS-3 design, one canister only and no variability in the biosphere.

The library of submodels will later be extended to incorporate the entire repository with spatial dependencies, site-specific hydrology and biosphere, alternative designs and variability in the biosphere etc. as the research and development program moves ahead from site screening and ranking, through the design optimization to the preliminary safety analysis report.

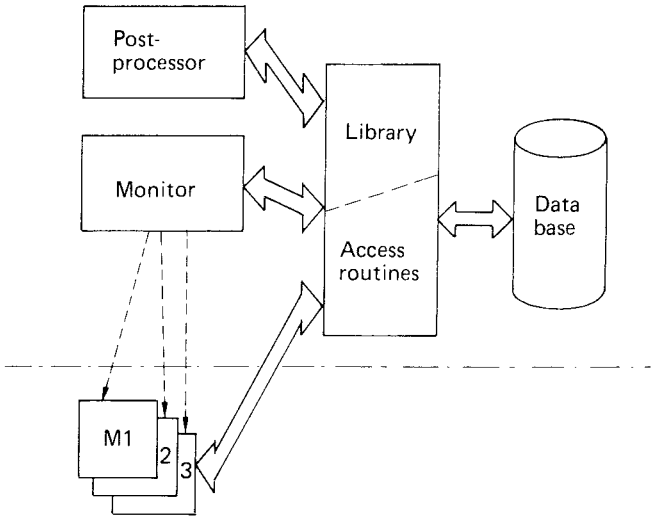


Figure 15-1. PROPER executive.

15.3 CONFIDENCE ENHANCEMENT

The degree of confidence that can be placed on results from models and computer codes is subject to some discussion among scientists in the waste management field. SKB is involved in R&D work and programs dealing with the

- validation of models, mainly the scientific ones,
- verification of the mathematical treatment in the models,
- calibration of simplified submodels or assessment models against the more elaborated scientific models.

The NUCDIF and TRUCHN transport models used in the KBS-3 study participated in the verification/validation study recently concluded in the IN-

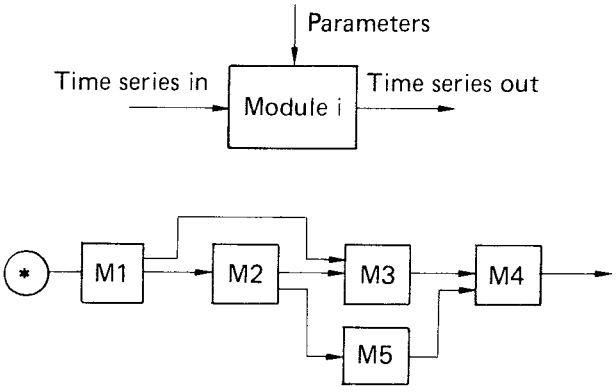


Figure 15-2. PROPER modular communication.

TRACOIN project initiated and managed by the Swedish Nuclear Power Inspectorate. The HYPAC/GWHRT code package developed within the SKB program is participating in the HYDROCOIN project and in predictions for the URL drawdown experiment at Lac du Bonnet, Canada, cf Chapter 13.

It is unlikely that the simplified models used in PROPER can be validated directly. They will have to be calibrated against scientific models that have been validated, verified and calibrated. SKB also takes part in the work conducted by the NEA Users' Group for Probabilistic Systems Analysis Codes where a level 0 code intercomparison is planned primarily to test the executive drivers of the participants' computer programs.

Software quality assurance procedures such as standardized and structured programming and standardized testing procedures will be implemented.

The development of regulations and acceptance criteria for radioactive waste disposal is the responsibility of the authorities. In the end the final choice and optimization of disposal concepts will have to be made taking full account of these criteria still under development.

16 THE STRIPA PROJECT

16.1 INTRODUCTION

To study the response of granitic rock to thermal loading, a series of experiments were conducted from 1977 to 1980 in the Stripa Mine, an old iron ore mine located in central Sweden. Adjacent to the ore excavations is a granite intrusion which is directly accessible at a level of approximately 350 m below the surface. The investigations were carried out as a cooperation between the US Department of Energy - through the Lawrence Berkeley Laboratory of the University of California - and the Swedish Nuclear Fuel and Waste Management Company, SKB. The main thrust of work under this Swedish - American Cooperative Project, SAC, was to develop techniques to measure certain properties and phenomena including thermomechanical, hydrogeological, geophysical and geochemical aspects.

The OECD/Nuclear Energy Agency International Stripa Project began in May 1980 on the strength of the results of the SAC program and the wide interest shown in other OECD member countries. At the present time nine countries participate in the project: Canada, Finland, France, Japan, Spain, Sweden, Switzerland, United Kingdom and the United States. Coordination is provided by the OECD/NEA and project management is carried out by SKB. Two phases of research have been agreed: Phase 1 was carried out from 1980 to 1984 and Phase 2 started in 1983 and is planned to be completed in 1986. Currently, negotiations are under way regarding a five year prolongation of the Stripa Project, starting in 1986.

16.2 RESEARCH PROGRAM 1980 - 1986

The NEA International Stripa Project includes a number of subprojects with different objectives, budgets and time schedules. Essentially, the research is concentrated to the following areas:

- detection and characterization of fracture zones
- radionuclide migration and groundwater characteristics
- behaviour of bentonite clay as a backfilling and sealing material.

The results obtained are presented in quaterly, internal and technical reports.

An international symposium, where the experiments and the results obtained were presented, was organized in Stockholm on June 4-6, 1985. The major conclusions presented at this symposium as well as later findings during 1985 are given below.

16.2.1 Detection and characterization of fracture zones

The dominant flow of groundwater in crystalline bedrock is taking place in existing fracture zones and it is therefore of outmost importance to characterize these zones.

The main objective of the research project "Crosshole Techniques for the Detection and Characterization of Fracture zones in the Vicinity of a Repository" is to develop nondestructive methods of bedrock investigation which can give information on the suitability of the rock mass for the disposal of radioactive wastes. Development is made of the high frequency electro-magnetic (radar), seismic and sinussoidal hydraulic testing methods. The results obtained with the electromagnetic and the seismic techniques are to be correlated with the relevant hydraulic properties. The capability of the techniques to determine the location, extent, and thickness of fracture zones will be examined. The program also intends to resolve questions concerning the possible resolution and the uniqueness of the models of bedrock obtained with these methods.

Measurements are performed with transmitter and receiver in a single borehole as well as in separate boreholes. Electromagnetic, seismic and hydraulic signals are measured in these configurations. A large disturbance such as a fracture zone will affect the transmission of signals. The location and orientation of fracture zones at large distances from the boreholes may be determined by performing tests from a large number of positions in the holes. The principle of borehole reflection radar and the patterns generated by plane and point reflectors are shown in Figure 16-1.

Some of the seismic investigations have been carried out at a regional scale at site Gideå located in the Northern part of Sweden. However, most field experiments using all three methods are carried out at a specially prepared site at the Stripa Mine. Six boreholes have been drilled in the form of a tilted pyramid.

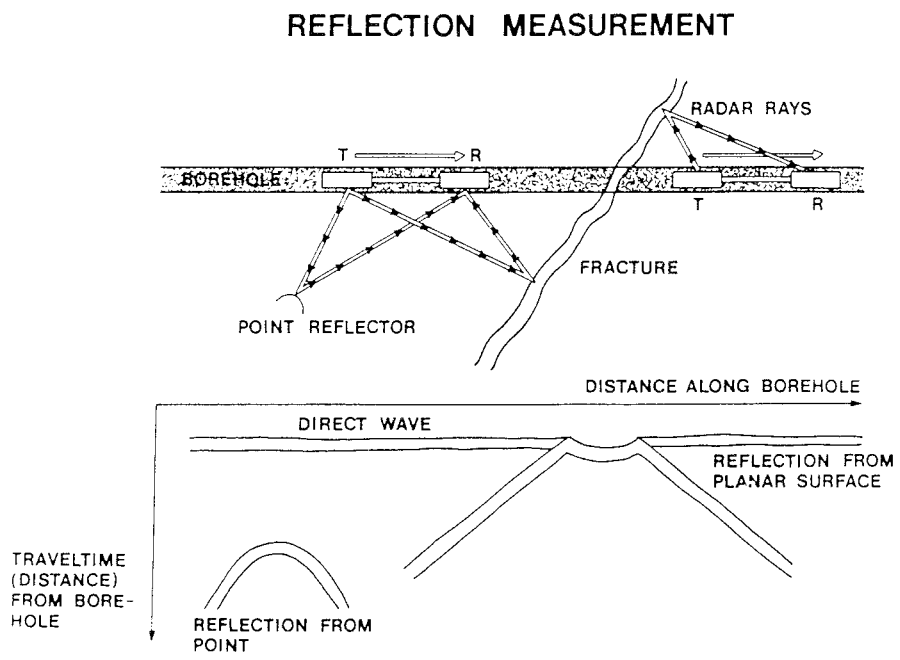


Figure 16-1. The principle of borehole reflection radar and the patterns generated by plane and point reflector.

The height and the base of the pyramid is approximately 200 m. A comprehensive program of "standard" single hole investigations have been performed in these holes to provide a data base with which the results obtained with the newly developed methods can be compared.

Conventional seismic investigation tools are being used in conjunction with a newly developed tomographic analytical method which can provide a 2D or 3D picture of the area being investigated.

Single hole reflection measurements and crosshole measurements have been performed using a radar system developed within the Stripa Project. Tests made with a high frequency version of the system (50 MHz) have given reflections from water filled boreholes which have a diameter of only 76 mm.

The hydraulic conductivity and the hydraulic head have been measured in the specially designed borehole configuration at Stripa. Crosshole hydraulic measurements have been performed using the most conductive zones of the holes as source zones. Sinusoidal tests are used where low frequencies (long periods) are measured first and then the frequency is increased until no further data is received. The results indicate that fissure - rock matrix interactions occur and groups of fissures have been delineated. Work is now in hand to correlate the hydraulic measurements to those from seismic and radar studies.

16.2.2 Radionuclide migration and groundwater characteristics

The migration modelling in the safety analysis for a repository in granitic rock is based on the assumption that if and when any radionuclides are leached from the waste, practically all of the important radionuclides will interact chemically or physically with the bedrock and will thereby be considerably retarded. The magnitude of this retardation depends upon the flow rate of the water, the uptake rates and equilibria of the reactions as well as the surface area in contact with the flowing water.

In an investigation called "Migration in a Single Fracture", both nonsorbing and sorbing tracers, simulating radionuclides, were injected into a single fracture. The arrival times and concentrations of these tracers were monitored in sample holes drilled along the fracture at a distance of about five meters away from the injection point. In addition, samples from the fracture close to the injection point were excavated by diamond drilling. An example of the analysis is shown in Figure 16-2.

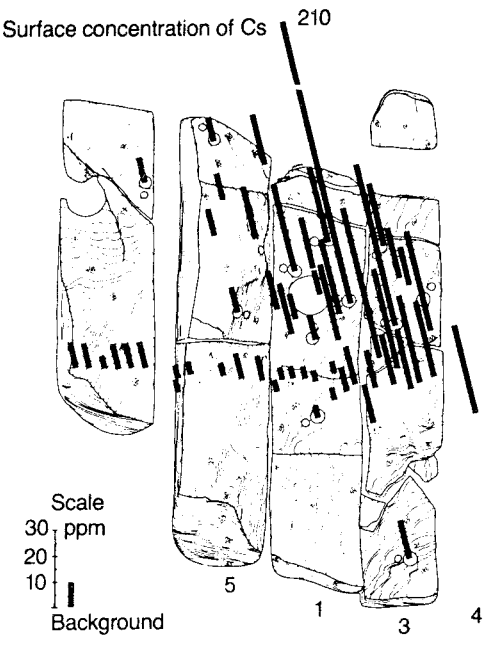


Figure 16-2. Distribution of Cesium around the injection point in the tracer experiment along a single fracture.

Figure 16-3. View of the experimental drift used in the 3D Migration Experiment.

The results from the experiment "Migration in a Single Fracture" together with supporting laboratory tests show that there are two mechanisms that are of importance for the magnitude of the retardation of the migrating radionuclides:

- diffusion into the rock matrix adjacent to the fracture and subsequent sorption on the inner surfaces
- channeling within a fracture i.e. only certain parts of the fracture conducts water.

The first mechanism considerably enhances the capacity of the rock to retard the radionuclides. The second mechanism counteracts the first by reducing the contact surface between the flowing water and the rock. It may also give rise to "fast" channels.

A "3D Tracer Migration Experiment" is currently in progress at Stripa. The objective is to get an understanding of the spatial distribution of water flow pathways in crystalline rock over a long distance (up to 50 m).

The experimental site is located at the 360 m level. Water flows constantly into the drift at this level since it is located well below the water table. The test site consists of two intersecting drifts with a total length of 100 meters. Three upwards vertical injection holes have been drilled to a depth of about 70 meters. Injection of nonsorbing tracers is carried out from a total number of nine separate zones in these holes with a higher permeability than the average rock. The entire roof and parts of the drift walls are covered with plastic sheets which are used for water sampling for further analysis. Figure 16-3 shows the experimental drift covered with plastic sheets.

Preliminary data from the "3D Migration Experiment" indicate that water does not flow uniformly in the rock over the scale considered. The water flow at this scale cannot be described as a homogeneous porous media flow. Instead, channeling seems to play an important role.

Part of the investigations at Stripa are aiming at determining the evolution of the Stripa groundwaters and to establish a general program for water sampling and analysis in crystalline rock. Water samples are taken from a maximum depth of 1200 meters below the surface. A large number of isotope methods have been tested in order to explain the origin and evolution of groundwater. It has been found that the concept of "groundwater age" is not very useful. The results from Stripa indicate that different elements can have different "mean residence times" because they may have different origins and different processes which affect their concentrations during the evolution of the groundwater. The investigations at Stripa have made considerable progress towards defining what those origins and evolutionary processes are, and how such concepts may be employed.

16.2.3 Bentonite clay as backfilling and sealing material

The so called "Buffer Mass Test" was initiated in 1980 and was completed in 1985. Six large boreholes with a diameter of 0.75 meters and a depth of about 3.5 meters, were used as deposition holes for simulated waste canisters surrounded by highly compacted bentonite and overlayed with a mixture of sand and bentonite. Part of the experimental drift was completely filled with the sand/bentonite mixture, see Figure 16-4. The purpose of the test was to verify the suitability and predicted functions of bentonite-based buffer materials under realistic conditions. Thus, temperatures, water uptake, swelling and water pressures were measured. The heater power was set to 600 W but supplementary tests at elevated power, 1200 and 1800 W, were also carried out. The deposition holes were excavated after time periods ranging from 10 to 40 months and the bentonite mass was carefully examined. In the same way, the filled-in portion of the drift

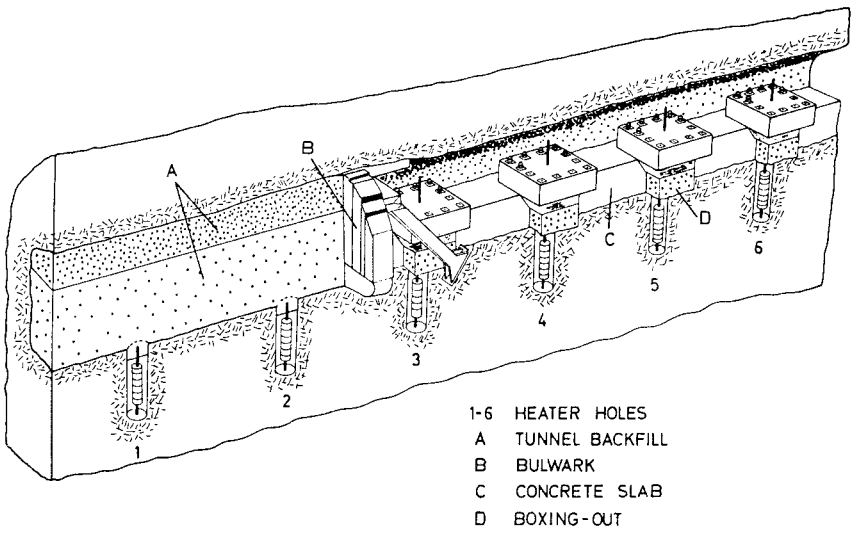


Figure 16-4. Main features of the Buffer Mass Test.

was excavated after 33 months of testing.

The experiment has been very successful and the overall results shows that the bentonite fills all voids after water saturation and swelling and thus verifies previously obtained laboratory data.

The main conclusions concerning the water uptake in the buffer material are

* moisture and also related swelling pressure will be evenly distributed despite orientation of water bearing structures in the adjacent rock,
* water uptake was controlled by water flow from rock and water pressure was low in the interface bentonite/rock,
* measured temperatures were in agreement with theory and laboratory data.

The densities, swelling pressures and deformation pattern in the buffer mass including the interface bentonite/backfill were in agreement with predictions.

The density of the backfilling especially in the upper region of the drift was low and the chemical interactions between the heater and possible effects on smectite alterations due to heat were vague or none.

The "Borehole, shaft and tunnel sealing" project which began in 1983 and will be completed in 1986, consists of four individual plugging tests using sodium bentonite. Two of the tests deals with borehole sealing, with the aim of assessing techniques used for inserting bentonite plugs in boreholes of varying length and to study the saturation rate of bentonite. In the shaft plugging test, bentonite/rock interactions are investigated to assess the sealing capabilities of bentonite. Finally, the tunnel plugging test is designed to demonstrate the construction phase and general isolating power of a full-scale backfilling and sealing exercise. It can be seen that each of these tests are designed to test the sealing ability of sodium bentonite by exposing the plugs to hydraulic gradients of varying magnitude. This ability is due to the very low hydraulic conductivity of sodium smectite, the major constitutent of the bentonite, and the high swelling pressure exerted on the surrounding rock mass. The swelling creates a tight contact with the rock and tends to close certain fractures in the rock adjacent to the bentonite plugs.

16.3 TENTATIVE RESEARCH PROGRAM 1986 - 1991

Negotiations between potential member countries regarding a continuation of the Stripa Project is currently underway. The tentative Phase 3 of the Stripa Project is scheduled to start on July 1st, 1986 and be completed on June 30, 1991.

The Phase 3 program extends the work carried out under Phases 1 and 2 and also enters new areas of research. An unexplored volume of granite (about 125 m x 125 m x 50 m) will be studied for which a combined deterministic/statistical flow model will be developed and compared with data from field measurements. This modelling approach will be used because previous investigations have indicated that an equivalent porous media model is inappropriate for similar volumes of fractured crystalline granitic rock. If successful, this will significantly enhance the confidence in the application of predictive mathematical models to site specific conditions.

Important parts of the Phase 3 program are the further development of the high resolution and directional radar together with high resolution borehole seismics.

Observations at Stripa on groundwater flow in fractures have revealed what appears to be randomly distributed channels. The present concept of these channels suggests that mixing of water occurs irregularly and that zones of stagnant or near stagnant water are present where diffusion controlled transport dominates. Phase 3 includes provision for further tracer experiments to investigate flow in fractures so that this important phenomenon, "channeling", can be more fully understood. A large scale tracer experiment

within the unexplored volume of granite will give results for further validation of mathematical models of the phenomenon.

New work on the estimation of fracture length and aperture using hydraulic measurement techniques will yield a tool to complement fracture analysis carried out in tunnel excavations. Again this is important in predicting water flow and in optimizing the engineering design. Also of importance is the use of sealing materials to restrict the migration of radionuclides from a repository. A project is included which comprehensively evaluates available sealants for use in the optimization of a repository.

The ultimate product of the Phase 3 program will be the applicability of the tools and know how to assess a potential radioactive waste repository site. Techniques will be available to carry out nondestructive site investigations, together with sealing methods designed to optimize the isolation potential of a repository established within crystalline granitic rock.

17 DOCUMENTATION

The results obtained in the R&D-program of SKB are documented at different levels:

- in technical memos and notes,
- in internal SKB working reports,
- in the series of SKB technical reports,
- in contributions to scientific journals, symposia and conferences in different subject areas,
- in reports requested by law and submitted to the Swedish Government or its authorities.

Further, the bulk of basic data from geological site-characterization activities, spent fuel studies etc. are collected and stored in a data base system at SKB presently under implementation.

17.1 TECHNICAL REPORTS

SKB Technical Reports and main reports like for instance the KBS-3 report are written in English. They are given a broad distribution to the scientific community in the nuclear waste field in order to get feedback to the program by the comments, discussions and contacts between specialists that they may give rise to. SKB Technical reports are also filed as microfish at IAEA in Vienna and available through them.

17.2 SKB DATA BASE SYSTEM

The large amount of data generated from the geological site investigations and from the laboratory experiments has to be administered in a systematic way. To this end a computerized data base is under development at SKB. The objectives are to

- accomplish a centralized storage of data directly connected to SKB, which has the overall program responsibility,
- promote quality assurance and long-term retrievability of data,
- collect and structure data sets in a common data base, that is readily available to the scientists doing R&D and assessment work for SKB,
- provide a tool for making statistical analyses of data.

The hardware of the system is a VAX-11/750 computer. A flexible system for loading, storing and retrieving data is under development based on a relational data base system called MIMER. The data are organized in separate data sets on geology, geophysics, hydrogeology and groundwater chemistry. For each of these areas the data generation and the data flow are being analyzed in detail to determine how, at what stage and with what quality control procedures data should be stored. The system will be ready for use in mid-86, but much work will be made also in the future to improve it.

A data communication system between the SKB VAX-computer and consultants working for SKB has been installed during 1985.

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Part III

Appendices

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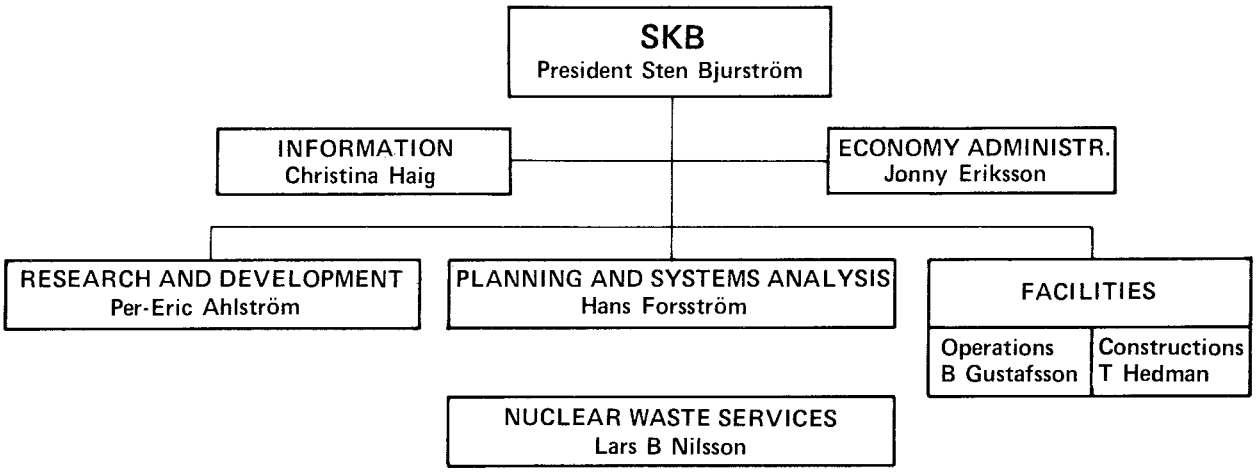
Appendix 1



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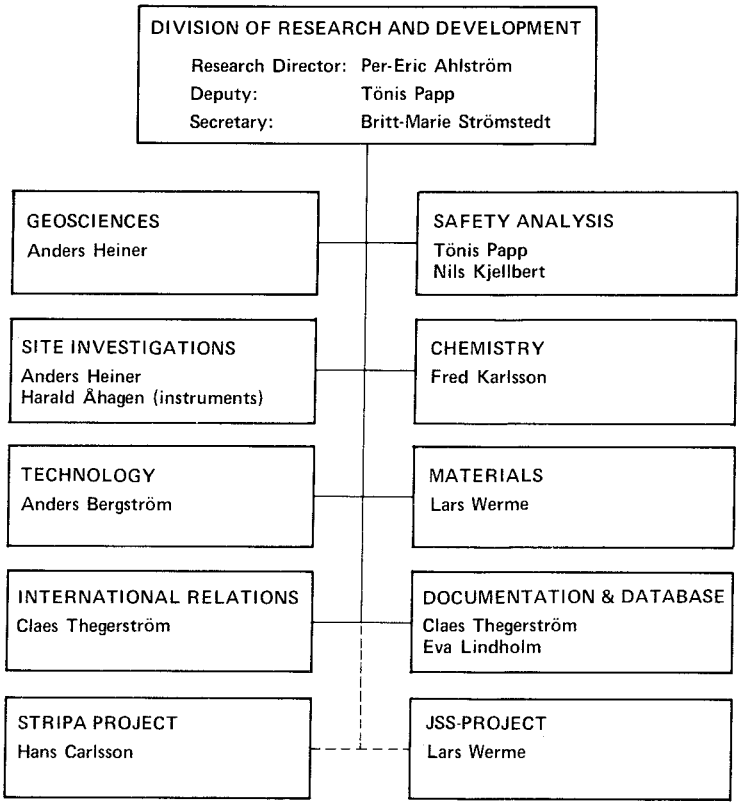

Organization of the R&D-division within SKB during 1985.

Staff-Changes

1. Britt-Marie Strömstedt was replaced by Maria Sommarlund on February 1, 1986.

2. Anders Heiner was replaced by Göran Bäckblom on April 1, 1986.

3. Karl-Erik Almén replaced Kurt Eriksson and Harald Åhagen on February 17, 1986, as responsible for the site-investigations and the development of instruments.

4. Claes Thegerström will be on leave from SKB as from May 5, 1986, to work at OECD/NEA in Paris. He will be replaced by Torsten Eng from June 1, 1986.

5. Hans Carlsson has been appointed manager for SwedPower/SKB Nuclear Waste Services as from August 1, 1986. He will be replaced by Bengt Stillborg. Kurt Eriksson left SKB September 1985.

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Summaries of Technical Reports from 1977 to 1984 are found in the following documents:

1977-78
TR 121
KBS Technical Reports 1 – 120.
Summaries. Stockholm, May 1979.

1979
TR 79-28
The KBS Annual Report 1979.
KBS Technical Reports 79-01–79-27.
Summaries. Stockholm, March 1980.

1980
TR 80-26
The KBS Annual Report 1980.
KBS Technical Reports 80-01–80-25.
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1981
TR 81-17
The KBS Annual Report 1981.
KBS Technical Reports 81-01–81-16.
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1982
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LIST OF SKB TECHNICAL REPORTS 1985

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TR 85-01

ANNUAL RESEARCH AND DEVELOPMENT REPORT 1984
Including Summaries of Technical Reports Issued during 1984
The Swedish Nuclear Fuel and Waste Management Co (SKB)
Stockholm, June 1985

TR 85-02

THE TAAVINUNNANEN GABBRO MASSIF. A COMPILATION OF RESULTS FROM GEOLOGICAL, GEOPHYSICAL AND HYDROGEOLOGICAL INVESTIGATIONS.
Bengt Gentzschein, Sven-Åke Larson, Eva-Lena Tullborg
Swedish Geological Company
Uppsala, January 1985

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POROSITIES AND DIFFUSIVITIES OF SOME NON-SORBING SPECIES IN CRYSTALLINE ROCKS
Kristina Skagius, Ivars Neretnieks
The Royal Institute of Technology
Department of Chemical Engineering
Stockholm, 1985-02-07

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David B Curtis
New Mexico, USA, March 1985

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DIFFUSIVITY MEASUREMENTS AND ELECTRICAL RESISTIVITY MEASUREMENTS IN ROCK SAMPLES UNDER MECHANICAL STRESS
Kristina Skagius, Ivars Neretnieks
The Royal Institute of Technology
Department of Chemical Engineering
Stockholm, 1985-04-15

TR 85-06

MECHANICAL PROPERTIES OF GRANITIC ROCKS FROM GIDEÅ, SWEDEN
Christer Ljunggren, Ove Stephansson, Ove Alm, Hossein Hakami, Ulf Mattila
Div of Rock Mechanics
University of Luleå
Luleå, Sweden, October 1985

TR 85-07

COMPLEX FORMING PROPERTIES OF NATURAL OCCURING FULVIC ACIDS
Part 1. Complexes with Cadmium, Copper and Calcium
Jacob A Marinsky, A Mathuthu, M Bicking, J Ephraim
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Buffalo, New York 14214
July 1985

TR 85-08

IN SITU ONE-YEAR BURIAL EXPERIMENTS WITH SIMULATED NUCLEAR WASTE GLASSES
Larry L Hench, Derek Spilman and T Buonaquisti
College of Engineering
Univ of Florida, Gainesville, USA
Alexander Lodding
Chalmers Univ of Technology, Gothenburg, Sweden
Lars Werme
SKB, Stockholm, Sweden

TR 85-09

CONCENTRATION AND DISTRIBUTION OF NATURAL RADIONUCLIDES AT KLIPPERÅSEN AND BJULEBO, SWEDEN
Björn Sundblad, Ove Landström, Rune Axelsson
Studsvik Energiteknik AB
1985-10-28

TR 85-10

CHEMICAL INTERACTIONS BETWEEN THE BENTONITE AND THE NATURAL SOLUTIONS FROM THE GRANITE NEAR A REPOSITORY FOR SPENT NUCLEAR FUEL
Bertrand Fritz and Marie Kam
Université Louis Pasteur de Strasbourg
Institut de Géologie
Strasbourg, France
July 1985

TR 85-11

HYDROCHEMICAL INVESTIGATIONS IN CRYSTALLINE BEDROCK IN RELATION TO EXISTING HYDRAULIC CONDITIONS. EXPERIENCE FROM THE SKB TEST-SITES IN SWEDEN
John Smellie, Nils-Åke Larsson
Swedish Geological Company, Uppsala, Sweden
Peter Wikberg
Royal Institute of Technology, Stockholm, Sweden
Leif Carlsson
Swedish Geological Company, Göteborg, Sweden
November 1985

TR 85-12

HYDROGEOLOGICAL INVESTIGATIONS AND TRACER TESTS IN A WELL-DEFINED ROCK MASS IN THE STRIPA MINE

Peter Andersson, Carl-Erik Klockars
Swedish Geological Company
Division of Engineering Geology
Uppsala 1985-11-29

TR 85-13

ANALYSIS OF HYDRODYNAMIC DISPERSION IN DISCRETE FRACTURE NETWORKS USING THE METHOD OF MOMENTS

Anders Rasmuson
Dep of Chemical Engineering
Royal Inst of Technology
Stockholm
June 20, 1985

TR 85-14

RADIONUCLIDE MIGRATION IN STRONGLY FISSURED ZONES – THE SENSITIVITY TO SOME ASSUMPTIONS AND PARAMETERS

Anders Rasmuson, Ivars Neretnieks
Dep of Chemical Engineering
Royal Inst of Technology, Stockholm
August 7, 1985

TR 85-15

DIFFUSION MEASUREMENTS OF CESIUM AND STRONTIUM IN BIOTITE GNEISS

Kristina Skagius, Ivars Neretnieks
Dep of Chemical Engineering
Royal Inst of Technology, Stockholm
1985-12-30

TR 85-16

THE CORROSION OF SPENT UO_2 FUEL IN SYNTHETIC GROUNDWATER

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October 1985

TR 85-17

SEALING OF ROCK FRACTURES A SURVEY OF POTENTIALLY USEFUL METHODS AND SUBSTANCES

Roland Pusch , Mikael Erlström, Lennart Börgesson
Swedish Geological Co, Lund
December 1985

TR 85-18

PROCEDURES FOR UNCERTAINTY AND SENSITIVITY ANALYSIS IN REPOSITORY PERFORMANCE ASSESSMENT

Kurt Pörn, Ove Åkerlund
Studsvik Energiteknik AB, Nyköping
1985-10-10

TR 85-19

EVALUATION OF SINGLE-HOLE HYDRAULIC TESTS IN FRACTURED CRYSTALLINE ROCK BY STEADY-STATE AND TRANSIENT METHODS

Jan-Erik Andersson, Ove Persson
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December 1985

AUTHORS OF SKB TECHNICAL REPORTS 1985 IN ALPHABETICAL ORDER

* The report is written by more than one person.

SKB ANNUAL REPORT 1985

Part IV

Summaries of Technical Reports Issued During 1985

SKB Technical Report No 85-01

ANNUAL RESEARCH AND DEVELOPMENT REPORT 1984

Including Summaries of Technical Reports Issued during 1984.

Stockholm June 1985

ABSTRACT

This is the annual report on the activities of the research and development division (formerly KBS-division) of the Swedish Nuclear Fuel and Waste Management Company, SKB. It contains background information on the Swedish nuclear waste management system. The research and development program of SKB is presented and a review is made of progress during 1984 in different areas of the program.

Lectures and publications during 1984 are listed in an appendix. The report also contains the summaries of all technical reports issued during 1984.

SKB Technical Report No 85-02

THE TAAVINUNNANEN GABBRO MASSIF. A COMPILATION OF RESULTS FROM GEOLOGICAL, GEOPHYSICAL AND HYDROGEOLOGICAL INVESTIGATIONS

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Sven-Åke Larson
Eva-Lena Tullborg
Swedish Geological Company

Uppsala, January 1985

ABSTRACT

The gabbro massif at Taavinunnanen, northern Sweden, is one of the study sites which has been investigated by the Swedish Nuclear Fuel and Waste Management Co (SKB) in order to study different geological environments within the scope of the longrange program for final disposal of spent nuclear fuel.

A 700 metres long borehole was drilled within the gabbro. Regional geophysics, geological mapping, petrographical studies, mineralogical studies of rock-forming minerals and of fracture fillings as well as hydrogeological tests were carried out.

The gabbro shows primary differentiation. Thus, the composition varies from gabbroic to ultrabasic.

The gabbro body is intersected by several granite dikes. These dikes exhibit a higher hydraulic conductivity and a higher fracture frequency than the gabbro. Comparison of hydraulic conductivity and fracture frequency in the gabbro itself indicates a high degree of sealing of the fractures mainly caused by smectites.

Calcite is almost lacking down to a depth of 75 metres, indicating a relatively rapid transport of surface waters down to this depth.

SKB Technical Report No 85-03

POROSITIES AND DIFFUSIVITIES OF SOME NON-SORBING SPECIES IN CRYSTALLINE ROCKS

Kristina Skagius
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Stockholm, 1985-02-07

SUMMARY

The diffusion of non-sorbing species in different rock materials and fissure coating materials has been studied on a laboratory scale. The non-sorbing species were iodide, Uranine and Cr-EDTA. The results show that the effective diffusivity of iodide in rock materials with fissure coating material is of the same magnitude or higher than the effective diffusivity of iodide in rock materials without fissure coating material. The results also show that it is not possible to give one value of the diffusivity in a rock material from a certain area. The variations in the rock material are too large. The estimated effective diffusivity of iodide in rock materials without fissure coating material was found to be in the range $1 \cdot 10^{-14}$ m^2/s to $70 \cdot 10^{-14}$ m^2/s.

The results also emphasize the necessity to distinguish between different porosities. The effective diffusivity is dependent on the "transport" porosity. This means that a higher determined total porosity does not always lead to a higher effective diffusivity.

There are also some indications that the relation between the effective diffusivity of a component in a rock material and the bulk phase diffusivity of the same component is not only depending on the properties of the rock material but also to some extent on the diffusing component.

SKB Technical Report No 85-04

THE CHEMICAL COHERENCE OF NATURAL SPENT FUEL AT THE OKLO NUCLEAR REACTORS

David B. Curtis
New Mexico, USA, March 1985

ABSTRACT

Uraniferous rocks in the Oklo mine contain the wastes of natural fission reactors, which were critical two billion years ago. Interment of these natural wastes is analogous to the storage of man-made spent reactor fuel for much longer times than are required for the radioactive elements to decay to innocuous levels. The natural nuclear products were formed *in-situ* within the grains of the mineral uraninite, the primary host for the natural wastes. Grains of uraninite are dispersed in a clay matrix and these phyllitic rocks are enclosed in sandstone. Uraninite has been remarkably stable during the extreme length of time that has passed since nuclear criticality. More than 90% of the fuel has remained in the spatial configuration that it had during criticality. Many nuclear products, including the actinides and the rare earth elements, have also largely remained in place. The stability of these elements can probably be attributed to their containment within in the stable uraninite host. Other nuclear products have not been effectively contained in the rocks of the reactors. These elements include technetium, the alkali and the alkaline earth elements. Their loss manifests their incompatibility within the uraninite host. They were probably excluded from this mineral in response to the extreme conditions produced during nuclear criticality. Many of the nuclear products removed from their site of production have been contained within the peripheral sandstone. This geologic environment provided effective containment of many of the reactor products. Massive deficiencies of lead represent a serious failure to contain a radioactive decay product within the geologic environment of the sandstones that comprise the Oklo ores.

SKB Technical Report No 85-05

DIFFUSIVITY MEASUREMENTS AND ELECTRICAL RESISTIVITY MEASUREMENTS IN ROCK SAMPLES UNDER MECHANICAL STRESS

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Stockholm, 1985-04-15

SUMMARY

At expected radioactive waste repository depths in the ground the rock is exposed to rather high stresses caused by the large overburden of rock. When drill-cores are taken up from the ground this overburden no longer exists. As a result of this there might be an increase in the porosity of the rock samples. The effective diffusivity measured in rock samples under atmospheric pressure in the laboratory would then be higher than the effective diffusivity in the rock "in situ".

To simulate the stress that may exist in the bedrock at large depths, diffusion experiments with iodide and electrical resistivity measurements in rock materials under mechanical stress have been performed. It was found that the diffusivity in rock samples at 300-350 bars stress was reduced to 20-70% of the value in the samples under atmospheric pressure.

SKB Technical Report No 85-06

MECHANICAL PROPERTIES OF GRANITIC ROCKS FROM GIDEÅ, SWEDEN

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Luleå, Sweden, October 1985

ABSTRACT

The elastic and mechanical properties were determined for two rock types from the Gideå study area. Gideå is located approximately 30 km north-east of

Örnsköldsvik, Northern Sweden. The rock types that were tested were migmatitic gneiss and migmatitic granite.

The following tests were conducted:

- sound velocity measurements
- uniaxial compression tests with acoustic emission recording
- brazilian disc tests
- triaxial tests
- three point bending tests

All together, 12 rock samples were tested with each test method. Six samples of these were migmatitic gneiss and six samples were migmatitic granite.

The result shows that the migmatitic gneiss has varying strength properties with low compressive strength in comparison with its high tensile strength. The migmatitic granite, on the other hand, is found to have parameter values similar to other granitic rocks.

SKB Technical Report No 85-07

COMPLEX FORMING PROPERTIES OF NATURAL OCCURING FULVIC ACIDS

Part 1. Complexes with Cadmium, Copper and Calcium

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July 1985

ABSTRACT

The experimental program developed in our earlier investigations of the protonation equilibria encountered with Armadale Horizons Bh and Suwannee River fulvic-acid has been employed in the present investigation of a Swedish fulvic acid source. Complications introduced by the polyelectrolyte nature and the degree of heterogeneity in the functional unit content of this natural organic acid molecule have been resolved as they were with the previous fulvic acid samples. The physical chemical properties of this fulvic acid have been compared with those resolved for the Armadale Horizons Bh and the Suwannee River fulvic acid as well.

The insight gained from these protonation studies and metal ion binding studies, also carried out in the course of this investigation, has led to the development of a model for interpretation of the binding of metal ions to fulvic acid at any pH, medium ionic strength, and metal ion and fulvic acid concentration level.

SKB Technical Report No 85-08

IN SITU ONE-YEAR BURIAL EXPERIMENTS WITH SIMULATED NUCLEAR WASTE GLASSES

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ABSTRACT

Two simulated nuclear waste glasses were corroded in an in-situ experiment in the Stripa mine up to one year at 90°C and ambient temperature. Changes in compositional in-depth profiles were measured using Fourirer transform infrared reflection spectroscopy, SIMS and Rutherford back-scattering.

For glass/glass interfaces, both glasses showed depletion of Na, Cs and B, but for the more corrosion resistant glass, the lower depletion is ascribed to the formation of a thin (0.2 nm) coherent and dense outer layer, enriched in Mg, Ca, Sr, Ba, Zn-Al), and Si, which impedes both ion exchange and network attack of the bulk underneath.

For the bentonite interfaces, cation exchange of Ca, Mg, Al and Fe from the bentonite for primarily Na and B is found to produce a glass surface that has three silicate-rich layers. The larger concentrations of M^{2+} and M^{3+} cations and the high silica content of the reaction layers result in a considerably retarded rate of ion exchange after the formation of these layers during the first three months of burial.

The granite interfaces showed the lowest rate of attack. This appears to be due to a large increase of Fe and Al within the glass surfaces exposed to granite.

The results obtained using Rutherford back-scattering confirm the results obtained using the other techniques for surface analysis. Analysis of burial sampels cast in steel mini-canisters show no significant effects associated with the steel canister-glass interface.

SKB Technical Report No 85-09

CONCENTRATION AND DISTRIBUTION OF NATURAL RADIONUCLIDES AT KLIPPERÅSEN AND BJULEBO, SWEDEN

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1985-10-28

ABSTRACT

The recipient areas Klipperåsen and Bjulebo are completely different. Bjulebo is a coastal site at the Baltic where two types of recipients are identified: a brackish bay and a lake. Klipperåsen on the other hand is an inland site where the recipients are bogs. One of these is the rest of a former lake and situated above a marked fracture zone in the bedrock.

Gamma ray surveys, which covered representative soil types, gave average exposure rate values of about 18 μR/h for both sites. This corresponds to a radiation dose of about 1.5 mSv/y.

Concentrations of Th and U were determined in rock, soil and plant samples and activities of Ra-226, Ra-228, Th-228, Cs-137 and K-40 in soil and plant samples. Average concentrations in Klipperåsen samples are for granite (dominating rock) 20.7 ppm, Th and 6.6 ppm U, for soil (upper zone) 5.6 ppm Th and 2.9 ppm U and for peat 1.8 ppm Th and 2.4 ppm U (dry weight). Fairly high concentrations were observed in some organic soil samples, 11.5 ppm Th and 13.1 ppm U. The nuclides in the U and Th decay chains are usually in disequilibrium, indicating different migration patterns for the radium, uranium and thorium isotopes. A much higher root uptake of radium isotopes as compared to uranium and thorium isotopes was observed.

The water quality and the content of U, Ra-226 and Rn-222 in ground- and surface water samples were determined. The Ra-226/U-238 activity ratio is in average 0.1 for the Bjulebo and 3.1 for the Klipperåsen water samples, i e the uranium content is roughly the same whereas the Ra-226 content is very low in the Bjulebo water samples.

SKB Technical Report No 85-10

CHEMICAL INTERACTIONS BETWEEN THE BENTONITE AND THE NATURAL SOLUTIONS FROM THE GRANITE NEAR A REPOSITORY FOR SPENT NUCLEAR FUEL

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ABSTRACT

The chemical evolution of a bentonite in contact with two different aqueous solutions from swedish granitic massifs has been studied by geochemical modelling of mass transfers.

The initial solutions are natural solutions from drillholes, one shallow diluted groundwater and one more saline solution from a deep aquifer in the granite. In order to model the behavior of bentonite in a repository for spent nuclear fuel (SKB project, Stockholm), the clay/solution ratio was taken very high (4 kg/kg or 10 moles of bentonite/kg H_2O). The solubility product of the reacting bentonite has been estimated from 25 to 200°C using a solid solution model.

With these datas the calculations showed that the bentonite does not remain stable with respect to the solutions along the heating curve (25 to 100°C). The alteration of the bentonite may change a lot the chemistry of the solutions and produce a secondary clay (smectite) and calcite, zeolite (laumontite) and amorphous silica. The mass transfer is always less important for the most saline water.

However, these mass transfers and chemical evolutions of the solutions correspond to an overall limited degradation of the bentonite phase because of an interne self buffering effect due to a high clay/water ratio. In particular no evolution to an illite type clay has been detected with no evidence for a potassium uptake in the exchangeable sites in a closed clay + water system.

SKB Technical Report No 85-11

HYDROCHEMICAL INVESTIGATIONS IN CRYSTALLINE BEDROCK IN RELATION TO EXISTING HYDRAULIC CONDITIONS. EXPERIENCE FROM THE SKB TEST-SITES IN SWEDEN

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November 1985

ABSTRACT

This report represents the compilation, discussion and interpretation of hydrochemical and hydraulic data resulting from the SKB test-site investigations carried out over a period of three years (1982-84). By systematically applying hydrological and geological considerations to each sampled horizon, it has been possible to differentiate between those groundwaters which are reasonably representative for the depth sampled, from those which have been subject to contamination from different sources. Groundwaters which are here considered representative are defined as those which show no evidence of mixing with other water sources, whether from drilling water, younger, nearsurface water, or other deeper groundwaters. As a consequence, only a very few sampled horizons can be considered worth serious hydrochemical attention. The lack of representative groundwater samples, whilst often due to technical problems or sampling from non-conductive sections of the boreholes, also illustrate the extremely complex geometry of the permeable fracture systems in crystalline bedrock, and thus the difficulty of establishing the nature and depth relation of the groundwater reservoir tapped.

Although the main findings of this study have revealed gross inadequacies in the hydrochemical programme, valuable experience has nevertheless been gained. Consequently, some of the improvements recommended in Section 7 of this report have been already implemented resulting in higher sampling standards and thus water samples which are much more representative for the hydrogeological environment under investigation.

SKB Technical Report No 85-12

HYDROGEOLOGICAL INVESTIGATIONS AND TRACER TESTS IN A WELL-DEFINED ROCK MASS IN THE STRIPA MINE

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Uppsala 1985-11-29

ABSTRACT

This report presents the results from hydraulic tests and tracer test in a well-defined, fractured, but low conductive granite in the Stripa mine. The purpose has been to study the properties of the rock and the fractures regarding hydraulic conductivity (K) and tracer transport.

The K-value of the rock has been determined by hydraulic single-hole tests. The heterogeneity of the rock has been studied by hydraulic cross-hole tests and the transport mechanisms and fracture properties by non-sorbing tracer test. The test configuration is cylindrical with injection in the centre hole and detection in 8 peripheral holes evenly distributed on the mantle area of a cylinder, radius 1.5 m.

The result from the single-hole tests in 1 m sections show a K-value between 1 E-9 and 7 E-12 m/s. The cross-hole tests indicate that the rock cannot be treated as a homogeneous, anisotropic, porous medium in the scale of this investigation. However, the method is a valuable help in identifying flow paths. The tracer test indicates that 3% of the total number of fractures are conducting water and that channeling occurs within the fracture planes. From the tracer test and the hydraulic tests, hydraulic fracture conductivity, flow porosity and longitudinal dispersion have been determined for different flow paths within the same distance from the injection hole.

SKB Technical Report No 85-13

ANALYSIS OF HYDRODYNAMIC DISPERSION IN DISCRETE FRACTURE NETWORKS USING THE METHOD OF MOMENTS

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June 20, 1985

ABSTRACT

Recent field investigations in crystalline rock give strong indications that water flows in largely isolated channels in fissured rock. The channels are located in fracture planes and may not connect to other channels in the same plane or at fracture intersections. In the present paper, hydrodynamic dispersion in such fracture networks is investigated using the concepts of residence time distribution (RTD) theory. It is shown that, from a set of simple relations, at least the first four statistical moments for the system response are easily obtained even for complicated networks. In particular, an equivalent dispersion coefficient may be calculated from the second central moment (variance). The effect of channeling generally decreases in systems with many mixing steps. A criterion, based on the coefficients of skewness and kurtosis, is derived for when the response of the system is in accordance with the diffusion-dispersion model. Examples show that this limit may not be obtained under realistic repository conditions in fissured rock.

SKB Technical Report No 85-14

RADIONUCLIDE MIGRATION IN STRONGLY FISSURED ZONES - THE SENSITIVITY TO SOME ASSUMPTIONS AND PARAMETERS

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August 7, 1985

SUMMARY

Radionuclides escaping from a repository for high level nuclear waste in crystalline rock may eventually be carried by the flowing water in fissure zones. In such zones the rock is broken in blocks of varying sizes and shapes. Also, the water velocity may vary considerably in such zones. A previously developed model which lumps the different blocks into a single PSEUDOBODY is tested by comparing it with an exact analytical solution which can account for the diffusion into blocks of any size distribution. The approximate simplified model which is based on a numerical scheme, and thus is more versatile, gives errors which are small compared to the "normal" variation in observed block size distributions and other data.

A method for determining an "average" Peclet number (or dispersion length) in a strongly varying velocity field is tested and found to give small errors compared to the present confidence limits in predicting dispersion data for large migration distances.

A simple criterion is proposed for defining the cut-off limit in the block size distribution, below which the blocks can be modelled as if they were in equilibrium with the flowing water.

A simple sensitivity analysis shows that much can be gained if the confidence limits for block size distribution, water flow rate, dispersion data, sorption data, and matrix diffusion data can be narrowed down.

SKB Technical Report No 85-15

DIFFUSION MEASUREMENTS OF CESIUM AND STRONTIUM IN BIOTITE GNEISS

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1985-12-30

SUMMARY

A significant retardation of radionuclides transported by flowing water from an underground repository can be expected if the nuclides are able to diffuse into the water filled micropores in the rock. This diffusion into the pores will also increase the surface available to interactions between the nuclides in the groundwater and the rock material, such as sorption. To calculate the retardation it is necessary to know the sorption properties and the diffusivities in the rock matrix for the radionuclides.

Diffusion experiments with cesium and strontium in biotite gneiss samples have been performed. Both the transport of strontium and cesium through rock sam-

ples and the concentration profiles of cesium and strontium inside rock samples have been determined. The result shows that diffusion of cesium and strontium occurs in the rock material.

A diffusion model has been used to evaluate the diffusivity. Both pore diffusion and surface diffusion had to be included in the model to give good agreement with the experimental data. If surface diffusion is not included in the model, the effective pore diffusivity that gives the best fit to the experimental data is found to be higher than expected from earlier measurements of iodide diffusion in the same type of rock material. This indicates that the diffusion of cesium and strontium (sorbing components) in rock material is caused by both pore diffusion and surface diffusion acting in parallel.

SKB Technical Report No 85-16

THE CORROSION OF SPENT UO_2 FUEL IN SYNTHETIC GROUNDWATER

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October 1985

ABSTRACT

Leaching of high burnup BWR fuel for up to 3 years showed that both U and Pu attain saturation rapidly at pH 8.1, giving values of 1-2 mg/l and 1 µg/l respectively. The leaching rate for Sr-90 decreased from about 10^{-5}/d to 10^{-7}/d but was always higher than the rates for U, Pu, Cm, Ce, Eu and Ru. Congruent dissolution was only attained at pH values of about 4.

When reducing conditions were inposed on the pH 8.1 groundwater by means of H_2/Ar in the presence of a Pd catalyst, significantly lower leach rates were attained.

The hypothesis that alpha radiolytic decomposition of water is a driving force for UO_2 corrosion even under reducing conditions has been examined in leaching tests on low burnup (low alpha dose-rate) fuel. No significant effect of alpha radiolysis under the experimental conditions was detected. Thermodynamically the calculated uranium solubilities in the pH range 4-8.2 generally agreed, well with the measured ones, although assumptions made for certain parameters in the calculations limit the validity of the results.

SKB Technical Report No 85-17

SEALING OF ROCK FRACTURES A SURVEY OF POTENTIALLY USEFUL METHODS AND SUBSTANCES

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December 1985

SUMMARY

The major water-bearing fracturs in granite usually form fairly regular sets but the extension and degree of connectivity is varying. This means that only a few fractures that are interconnected with the deposition holes and larger water-bearing structures in a HLW repository are expected and if they can be identified and cut off through sealing it would be possible to improve the isolation of waste packages very effectively.

Nature's own fracture sealing mechanisms may be simulated and a survey of the involved processes actually suggests a number of possible filling methods and substances. Most of them require high temperature and pressure and correspondingly sophisticated techniques, but some are of potential interest for immediate application with rather moderate effort. Such a technique is to fill the fractures with clayey substances which stay flexible and low-permeable provided that they remain physically and chemically intact. Clay grouting has been tried for many years with very moderate success by applying a constant, static pressure. It is demonstrated in the report that effective grouting requires a very low viscosity and shear strength of the substance and this can be achieved by mechanical agitation as demonstrated in this report. Thus, by superimposing static pressure and shear waves induced by percussion hammering at a suitable frequency, clays and fine-grained silts as well as cement can be driven into fractures with an average aperture as small as 0.1 mm. A suitable consistency of the grouts is that corresponding to their Atterberg liquid limit.

Experiments were made in the laboratory using concrete and steel plates, and a field pilot test was also conducted under realistic conditions on site in Stripa. They all demonstrated the practicality of the "dynamic injection technique" and that the fluid condition of the grouts yielded complete filling of the injected space to a considerable distance from the injection point. The field test indicated a good sealing ability as well as a surprisingly high resistance to erosion and

piping. Long term tests are required, however, to demonstrate the durability of such sealings and it is also required to show that the fillings are chemically stable in repository environment.

SKB Technical Report No 85-18

PROCEDURES FOR UNCERTAINTY AND SENSITIVITY ANALYSIS IN REPOSITORY PERFORMANCE ASSESSMENT

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1985-10-10

ABSTRACT

This report was prepared as an account of work sponsored by the Swedish Nuclear Fuel and Waste Management Co. The objective of the project was mainly a literature study of available methods for the treatment of parameter uncertainty propagation and sensitivity aspects in complete models such as those concerning geologic disposal of radioactive waste. The study, which has run parallel with the development of a code package (PROPER) for computer assisted analysis of function, also aims at the choice of accurate, cost-effective methods for uncertainty and sensitivity analysis. Such a choice depends on several factors like the number of input parameters, the capacity of the model and the computer resources required to use the model.

Two basic approaches are addressed in the report. In one of these the model of interest is directly simulated by an efficient sampling technique to generate an output distribution. Applying the other basic method the model is replaced by an approximating analytical response surface, which is then used in the sampling phase or in moment matching to generate the output distribution. Both approaches are illustrated by simple examples in the report.

SKB Technical Report No 85-19

EVALUATION OF SINGLE-HOLE HYDRAULIC TESTS IN FRACTURED CRYSTALLINE ROCK BY STEADY-STATE AND TRANSIENT METHODS

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December 1985

ABSTRACT

The results from a large number of single-hole packer tests in crystalline rock from three test sites in Sweden have been analysed statistically. Average hydraulic conductivity values for 25 m long test intervals along boreholes with a maximal length of about 700 m are used in this study. A comparison between steady state and transient analysis of the same test data has been performed.

The mean value of the hydraulic conductivity determined from steady state analysis was found to be about two to three times higher compared to values obtained in transient analysis. However, in some cases the steady state analysis resulted in 10 to 20 times higher values compared to the transient analysis. Such divergence between the two analysis methods may be caused by deviations from the assumed flow pattern, borehole skin effects and influence of hydraulic boundaries.