SKB

R&D-PROGRAMME 86

Handling and final disposal of nuclear waste.

Programme for research development and other measures

September 1986

Summary

SVENSK KÄRNBRÄNSLEHANTERING AB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
P.O.BOX 5864 S-102 48 STOCKHOLM SWEDEN

Handling and final disposal of nuclear waste.

Programme for research development and other measures.

September 1986

Summary

CONTENTS

1 BACKGROUND AND GENERAL PREMISES

The Act on Nuclear Activities (SFS 1984:3) obligates the owners of the Swedish nuclear power plants to jointly prepare a comprehensive programme for the research and development work and other measures required for the safe management and disposal of the waste from nuclear power.

The nuclear power utilities have commissioned Svensk Kärnbränslehantering AB - SKB (Swedish Nuclear Fuel and Waste Management Company) - to prepare the research programme prescribed by the Act on Nuclear Activities. The programme, which is presented in this report, provides an outline of all research activities up to implemented final disposal. A more detailed research programme is described for the period 1987-1992.

The programme also presents in brief some research results obtained after the publication of the KBS-3 report in May 1983.

The comments made in connection with the review of the KBS-3 report, as well as guidelines issued by the Government and concerned authorities, have been taken into account in preparing the programme.

Premises

The goal of radioactive waste management in Sweden is to dispose of all radioactive waste products, generated at the Swedish nuclear power plants, in a safe manner.

The following general guidelines apply to the waste management system:

- The radioactive waste products shall be disposed of in Sweden.
- The spent nuclear fuel shall be temporarily stored and finally disposed of without reprocessing.
- Technical systems and facilities shall fulfil high standards of safety and radiation protection and satisfy the requirements of the Swedish authorities.
- The systems for waste management shall be designed so that requirements on the control of fissionable material can be fulfilled.
- In all essential respects, the waste problem shall be solved by the generation that utilizes electricity production from the nuclear power stations.
- A decision on the design of the final repository for spent nuclear fuel shall not be taken until around the year 2000 so that it can be based on a broad body of knowledge.
- The necessary technical solutions shall be arrived at within the country, at the same time as available foreign knowledge shall be gathered.
- The conduct of the work shall be guided by the regulatory authorities' continuous review and assessment and the directives issued by them.
- The activities shall be conducted openly and with good public insight.

Three main types of waste are generated in the Swedish nuclear power plants: Spent nuclear fuel, operating waste and decommissioning waste. A simplified scheme of the necessary components in a complete management and disposal system for these wastes is shown in Figure 1.

Central parts of the waste management system have already been taken into operation or are under construction. These include the transportation and handling system, the central interim storage facility for spent nuclear fuel (CLAB) and the final repository for reactor waste (SFR). For these facilities, the research and development stage has already essentially been passed. The programme presented here is therefore concerned mainly with treatment and disposal of spent fuel.

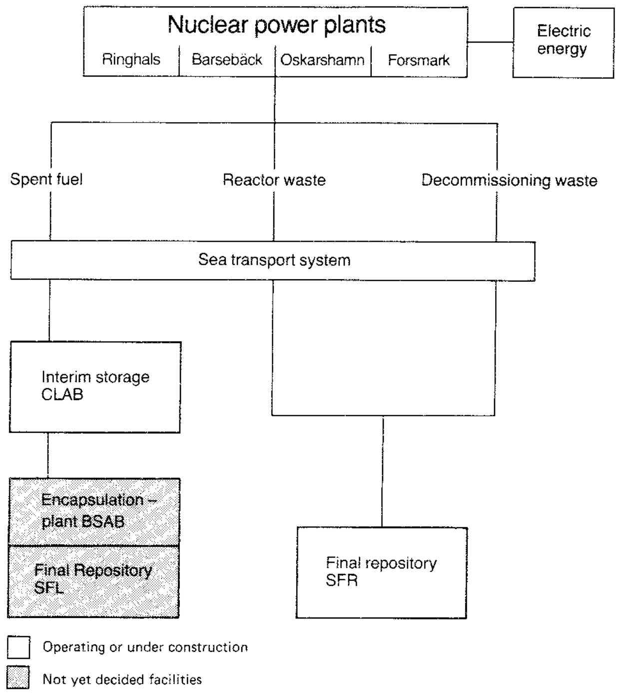

Figure 1. The Swedish Waste Management System.

Goal of the research

The research programme is aimed at obtaining the necessary information base for a site-specific siting application for a final repository for spent nuclear fuel around the year 2000. Until then a system optimization must be carried out so that a system adapted to a given site can be specified.

The research and development work shall be conducted with due regard to:

- environment and safety,
- economy,

- comprehensiveness,
- flexibility,
- relevance,
- broad acceptance in society, both among specialists and government authorities and among the general public.

The requirement on comprehensiveness in the research means that various alternatives shall be studied and evaluated. Flexibility should therefore be retained for as long as possible. Effective R&D requires defined goals and delineated frames. It is therefore important to select and focus the research work in such a manner that priority is given to the most interesting and realistic alternatives. The research must be continuously related to those phenomena that are of relevance to the function and safety of the final repository.

Up to 1984, the main goal of SKB's research was to demonstrate that a safe final disposal of spent nuclear fuel can be effected in Sweden. Efforts were concentrated on a specific method. This is described in the KBS-3 Report. The safety account in KBS-3 is based on a number of pessimistically chosen premises. Credit is not taken for inadequately understood conditions and factors if they act in a favourable direction. Methods and data have consistently been selected to provide an estimated upper limit for the impact of the final repository on the biosphere. The safety analysis in KBS-3 therefore contains considerable margins of safety that were not possible to quantify at the time.

One important goal of the continued R&D work is to gain better knowledge of the actual margins of safety. Improved knowledge in this respect provides a better basis for an optimization of the final disposal method and allows greater freedom in the choice of a repository site.

Final disposal principles

The concept "final disposal" entails that the waste is to be isolated without any requirements on surveillance and in such a manner that it is difficult or impossible to get at. A monitored storage is included as an inescapable link in the handling chain. It can be prolonged over a very long period of time without any major technical or safety-related problems. Sooner or later, however, the waste must be transferred to a repository without supervision and the repository must be sealed. We cannot demand or assume that future generations will bear the burden of resource-consuming surveillance and maintenance of the repository. A repository that is dependent for its safety on continuous surveillance and maintenance measures cannot be regarded as a final repository.

A number of different principles for final disposal of radioactive waste have been proposed in the international discussion.

For spent fuel, and other very long-lived radioactive waste, disposal at great depth (several hundred metres or more) in geological formations is the principle that is prioritized by all countries that conduct extensive research and development on disposal of radioactive waste. It is also the only alternative that is deemed available and feasible as far as Sweden is concerned within the foreseeable future.

Accordingly, the research programme has been oriented towards the final goal that final disposal of the spent nuclear fuel shall be achieved deep down in the Swedish bedrock. The KBS-3 report has described one method based on this principle. The method has been approved from the standpoint of safety and radiation protection.

The purpose of SKB's research and development is to provide a broad information base for the final choice of method. In principle, the work is not bound to any given method. It is aimed, in a generic way, at the study of matters of importance to many alternatives in rock. This means that a number of different methods are being and will be studied and evaluated in present and future research.

2 R&D PROGRAMME

Programme overview
Safety in connection with final disposal in crystalline rock or other geological formations is provided by a system of barriers that isolate the waste from the biosphere. The barriers prevent or retard the dispersal of radioactive materials from the final repository. Some of the barriers are natural (the rock) and some are engineered (canister, buffer and waste matrix). The research concerns the properties and integrated performance of these barriers with the aim of obtaining a basis for an optimized choice of barrier system and repository site.

Not until encapsulation of the spent fuel begins is there any essential limitation in freedom of choice with regard to waste management method. This is because the choice of encapsulation material and method is closely linked to the choice of final disposal method. Thus, a crucial decision-making time, as far as the flexibility in the system is concerned, is the start of construction of the encapsulation plant for the spent fuel. This is therefore planned to take place approximately simultaneously with the start of construction of the final repository, which is in turn planned to take place around the year 2010.

Figure 2 shows an overall timetable for the R&D, technology development and other measures that are required prior to the start of construction.

Up to the mid-1990s, goal-oriented research is planned on alternative designs of the barrier system and on the fundamental phenomena of importance for safety, optimization and choice of system and site. At the same time, the necessary development of analysis models is being pursued.

In parallel with this, the general area characterization that has been going on since the end of the 1970s will be completed. In the early 1990s, a couple of sites will be selected for detailed investigations. These investigations should not be begun later than 1993 for the sites that could be candidates for a siting application in the year 2000.

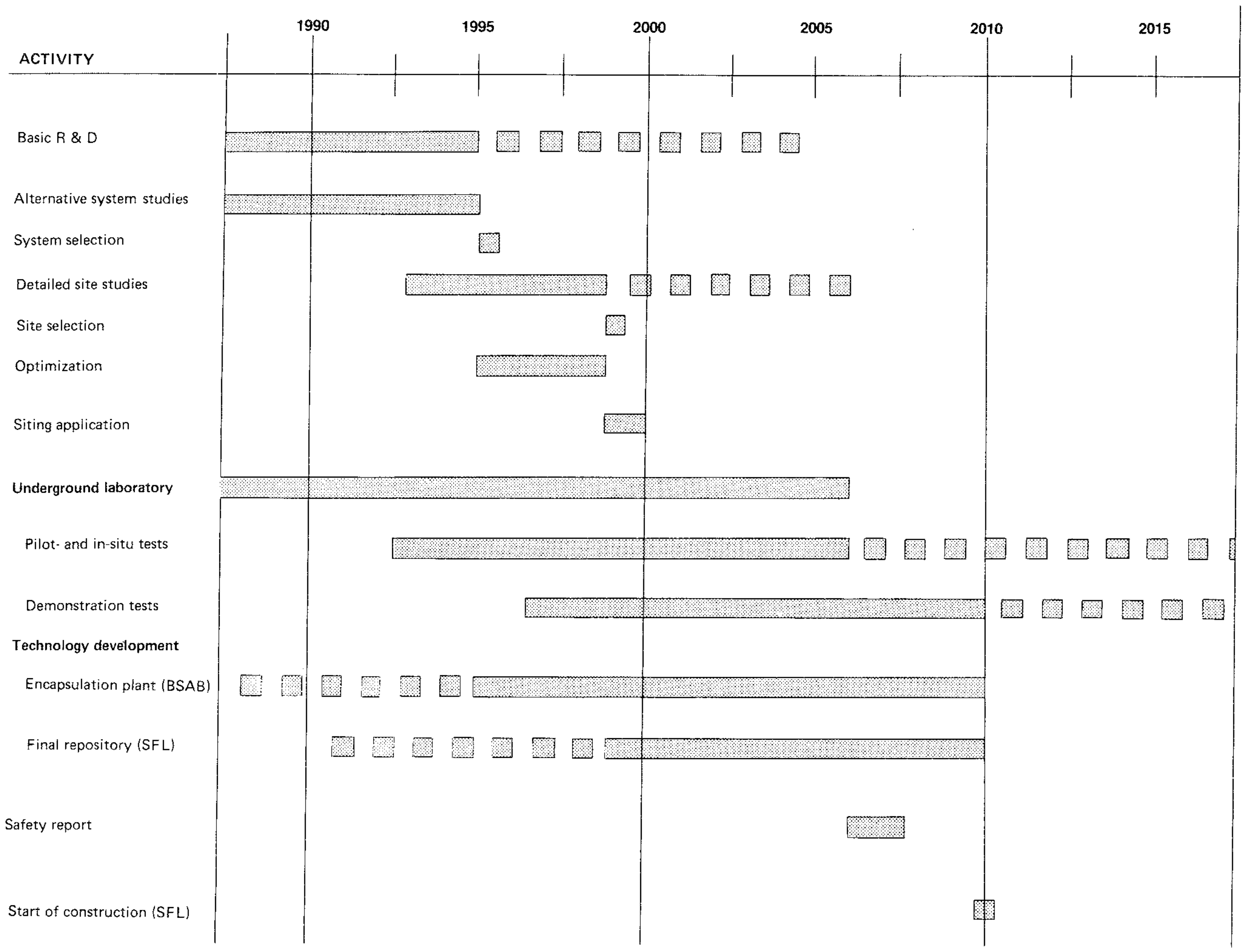

Figure 2. Overall timetable for measures up to the start of construction of the final repository and the treatment station.

In the mid-1990s, the studies of barrier systems will be summarized and one or possibly two main alternatives will be chosen as a basis for a site- specific optimization of the final repository system. The optimization will be carried out until 1998, when work will begin on a siting application. The application will be submitted in the year 2000.

To sum up, the choice of system is planned for the mid-1990s and the choice of site for 1998.

For the period 2000-2010, the emphasis is foreseen to lie on technology development and demonstration of the function of the chosen system. Pilot tests and long-term in-situ tests should be begun in good time before the year 2000 in order to provide support for a siting application. These tests should be conducted in the underground research laboratory that is presented in greater detail in a following section. Larger-scale and integrated demonstration trials will probably be conducted at a later stage either in the underground research laboratory or on the selected repository site. The design of these trials is dependent on the development of the technology. Certain demonstrations and in-situ tests are also foreseen during the construction phase.

Research and development within fundamental fields of importance for safety and long-term function will continue even after the mid-1990s. But their scope is expected to decrease and the emphasis to shift towards phenomena of special importance for the system(s) chosen as the main alternative(s).

The results of continued detailed observations on the selected site, of tests in the underground research laboratory, of supplementary basic research, of demonstration trials and of ongoing technology development will be summarized in a safety report that will be reviewed by the authorities prior to the start of construction.

Alternative studies

An important task over the next few years will be to study various alternative designs.

The barriers can be varied in different ways by choice of material and design. Similarly, adaptation of the barriers to the site can be accomplished in several ways for the different basic disposal alternatives. If the fact that such factors as repository depth, rock types etc can vary is also taken into consideration, a very large number of possible variants are obtained. A narrowing-down of the studied alternatives must be made continuously in order to obtain a manageable basis for an optimal design of the final repository.

During 1986-87, SKB is conducting a performance and cost analysis of the WP-Cave, which is one example of an alternative departing from KBS-3. Other interesting alternatives are horizontal emplacement of the canisters in full-face bored tunnels (studied by NAGRA in Switzerland); disposal in very deep holes drilled from the surface and plugged at the top; disposal in long tunnels at great depth in the rock beneath the Baltic Sea etc.

Within the framework of a given basic alternative, it is possible to choose from different materials and designs of the canister and buffer material. SKB will carry out an inventory of possible alternative canister and buffer materials.

Studies of steel as a canister material have already been carried out abroad in a number of countries. SKB is conducting certain supplementary studies of local corrosion in steel and is hereby cooperating with researchers in Great Britain and Switzerland.

Fundamental studies of various clay materials are being conducted in cooperation with researchers in France. These studies will be completed during the coming six-year period.

Properties of spent nuclear fuel

Studies of spent nuclear fuel in a final repository environment is a very important part of the research programme. The waste form - spent nuclear fuel - is given in the alternatives that are to be studied. The emphasis lies on experimental studies of the interaction between fuel, groundwater and substances that may be dissolved in the groundwater. This work has been going on for many years and will continue for a considerable time. The research aims at clarifying the chemical-physical processes that govern the dissolution of radionuclides from the fuel.

Besides the experimental work, considerable work is also being done on developing theoretical models. The goal is to have a model that can describe the process of fuel dissolution and be used in an optimization of the barrier system by the mid-1990s.

The studies of spent fuel are being conducted in close contact with similar projects in other countries, mainly Canada and the USA. Other major nuclear power countries have reprocessing of the spent fuel as their main alternative and are consequently concentrating their research on vitrified high-level waste from reprocessing.

Geoscientific studies

Research and development in the geoscientific field is being concentrated on areas that are of central importance for design, safety assessment and site selection.

These areas are:

- Groundwater movements in the rock.
- Stability of the rock.
- Studiy-site investigations.
- Transport of radionuclides with the groundwater.

In connection with the work within these areas, further efforts are being made to refine mathematical methods and measurement technique for geoscientific investigations.

Groundwater movements in the bedrock are being studied within a number of projects. The most important are:

- the international Stripa project, where a third phase is being carried out during the period 1986–1991,
- field studies of fracture zones at Finnsjön in Uppland and on Ävrö in Småland,

- studies of fractures, fracture zones and water seepage in tunnels on current building projects at different places in the country,
- running observations and measurements at the final repository for reactor waste, SFR, at Forsmark,
- supplementary measurements on the study-sites previously studied by SKB.

In connection with these field studies, a great deal of work is being done to develop models to describe groundwater flow. Several different approaches are being tried for the purpose of achieving greater precision in the safety assessment.

SKB has also reached a preliminary agreement with the Canadian research organization AECL to take part in their underground research laboratory, URL, in Manitoba. The results obtained from this project will complement the studies mentioned above.

The stability of the bedrock is being studied in a recently initiated investigation of a neotectonic zone of movement near Lansjärv in Norrbotten in the north of Sweden. The project includes field studies of seismology, rock mechanics etc. It also includes analyses to determine the consequences of earthquakes, ice ages etc.

Study-site investigations

Geological investigations on different scales have so far been carried out on a total of 14 sites. Relatively extensive investigations have been carried out on eight study-sites. Limited surface investigations, and in some cases also limited drillings, have been carried out on an additional six sites. On the basis of these investigations and other preliminary studies and reconnaissances, it can be concluded that there are good possibilities of finding sites in Sweden that possess the geological characteristics required for the construction of a safe final repository.

The bedrock on the study-sites where more extensive investigations have been carried out consists of gneissic or granitic rock types. The data currently available on these types of rock are judged at present to be sufficient to permit a comparison between different sites and an assessment of existing variations. There is, however, reason to supplement the data by special in-depth investigations on one or more of the already investigated study-sites.

In connection with the evaluation of previous results and experience on which this research programme has been based, the question of the comprehensiveness of the geological investigations has also been considered, for example the need to study basic rock types, such as gabbro. The results of investigations and general experience of gabbro show that it is relatively difficult to find sufficiently large homogeneous formations among gabbro massifs. These massifs are furthermore relatively scarce in comparison with gneiss or granite areas. The benefit of further knowledge concerning gabbro is judged to be marginal, and further investigations of this rock type are not a prerequisite for the implementation of the final disposal scheme.

Underground research laboratory

The planned R&D work shall be of high quality, have a balanced scope and be carried out effectively. These demands have been evaluated based on the experience that has been gained from the study-site investigations, from the Stripa project, from the SFR project and otherwise from the geohydrological studies in particular. An evaluation of facts, demands and appraisals clearly points towards the need for more detailed and comprehensive investigations. The site where these are performed should possess the necessary geological characteristics and be undisturbed geologically. In order to meet these and other needs, an underground research laboratory is planned. The purpose of this laboratory is to:

- Provide a base for development and testing of the detailed investigation methods that are to be used in detailed site investigations in the 1990s.
- Study in detail the groundwater flow within a larger region (than in Stripa) and how this flow is affected by shaft sinking or tunnelling.
- Serve as a site for geoscientific investigations and experiments.
- Permit tests of nuclide transport (with the groundwater) to be carried out within well-characterized and representative regions.
- Provide an opportunity for pilot tests, in-situ tests and large-scale demonstrations.

Some of these purposes will already be fulfilled during the preliminary investigation and construction phase. The data obtained at that stage will provide a basis for validation and refinement of mathematical models for e g groundwater flow. They will also permit validation and improvement of the preliminary investigation methods used. Other purposes will not be fulfilled until the laboratory stands completed.

The underground research laboratory should be available when Stripa phase 3 is concluded, ie at the beginning of the 1990s. This means that the preparatory work should start immediately. Activities at the research laboratory will probably extend over a period of at least 15 years. Experience from Stripa, URL and SFR should be taken into account in planning, preliminary investigations and design work.

An underground research laboratory should be situated on a site with suitable geology. In addition, it is important that the site should have some infrastructure and that service is available. For these reasons, among others, the suitability of one of the nuclear power station sites, in particular Simpevarp at the Oskarshamn station, will be explored.

Chemistry

Transport of radioactive substances from the waste to the biosphere via the groundwater is the most important transport mechanism. The chemical parameters that control this process are therefore as important for safety as the groundwater movements. The chemical parameters are also of crucial importance for possible corrosion of canister material. Further chemistry studies are therefore an important part of the R&D work. The chemistry has a bearing on all parts of the barrier system, both engineered and natural barriers and their function.

Natural analogues

In order to study how radioactive substances are transported with the groundwater, various tests are being conducted with tracer substances. The tests provide fundamental information on water flows in fractures and on chemical interaction between dissolved substances and fracture or rock minerals. Such tests have been conducted and are being conducted within the Stripa project. Further tests are planned.

However, the tests that are being conducted in the field and in the laboratory can, for natural reasons, only be performed on a relatively short time scale and the results can therefore not be used directly to validate calculation models for radionuclide transport on the longer time scale that is relevant for a final repository. In order to obtain data that are more representative of this longer time scale, so-called "natural analogues" are being studied. These include the transport of naturally occurring radioactive materials in the bedrock. SKB is participating together with NAGRA in Switzerland and the Department of the Environment in Great Britain (UKDOE) in a study of a uranium mineralization and a thorium mineralization (with very high contents of uranium and thorium, respectively) at Poços de Caldas in Brazil. Further studies of similar natural analogues are underway or planned.

Model development

The knowledge and data generated by the R&D work have to be systematized and coupled to theories and models. These models provide a mathematical description of various mechanisms and processes and are necessary tools for analysis and optimization of the final repository system and for description of its long--time performance. Work on the development of such models is carried on continuously in conjunction with the experimental work in laboratories and in the field. Examples particularly worth mentioning here are models for groundwater flow in fractured rock, for nuclide transport in the near field, in the rock and in the biosphere and integrated systems of models for performance and safety assessments.

3 SITE SELECTION FOR THE FINAL REPOSITORY

Before a site is chosen for the final repository, more detailed investigations are required than those that have thus far been carried out on the study-sites. Only on the basis of such investigations can the necessary information be obtained for the site-related optimization of the final repository and the preparation of a siting application. Detailed investigations should be carried out on two sites during the 1990s. The investigations should cover a period of at least five years and be completed by no later than 1998 to provide a basis for the final choice of a site for the final repository. The investigations at this site will then continue for several more years.

Before a site is chosen for detailed investigation, a general geological survey equivalent to a study-site investigation should be carried out. This means that investigations on any new sites are planned to take place no later than during the period 1990-1992.

The basis for the selection of sites for detailed investigations will be the study site investigations that have been conducted during the past ten years and the further inventories and reconnaissances that SKB will have done up to that stage. The latter will be completed during the period 1986-1989. If conditions prove suitable, the site for the research laboratory may be one of the sites chosen for detailed investigations.

4 INTERNATIONAL COOPERATION

A common international view on the scientific bases for safety in handling and final disposal of nuclear waste is of great value. Development work within the nuclear waste management field is therefore pursued to a large extent in international cooperation, interaction and exchange. SKB is involved in this work in many ways. Thus, SKB is the responsible executive organization for three international projects, namely:

- The Stripa project, which is being conducted in the Stripa mine with nine participating countries within the OECD/NEA. The project started in 1980 and is planned to run until 1991.
- The JSS project, which concerns studies of high-level waste glass from France. Participating countries are Japan, Sweden and Switzerland. The project started in 1982 and will be concluded in 1987.
- The Poços de Caldas project, which concerns studies of natural analogues on a site near Poços de Caldas in Brazil. Participating countries besides Brazil are Switzerland, Great Britain and Sweden. The project started in 1986 and is planned to run until 1989.

In addition, SKB has bilateral agreements on information exchange and cooperation with a number of sister organizations in other countries (NAGRA in Switzerland, CEA in France, DoE in the United States, AECL in Canada and Euratom in the EEC).

Finally, SKB is participating in several other international projects and in work within the IAEA and the OECD/NEA.

5 EXECUTION OF THE PROGRAMME

The programme will be executed under the leadership of SKB, who is responsible for planning, initiation and coordination of the work. The R&D work will mainly be carried out under contracts to research institutions at universities and institutes of technology, to industry consultants or other Swedish and foreign groups with the necessary competence. SKB will be responsible for continuous documentation and compilation of the results and for their application.

The plan of large projects, as well as results and their application, will be discussed in reference groups including outside specialists. The results will be continuously reported in SKB Technical Reports, in scientific journals and at international conferences and seminars. In this way, a review and assessment of the scientific quality of the work will be obtained.

Safety, performance, feasibility and development potential will be continuously analyzed for different alternative system designs in integrated performance assessment groups consisting of persons from both SKB and instituions and consulting firms engaged in the work.

The work in reference and integrated performance assessment groups, and the review and assessment of the results of the R&D work, will provide a basis for a continuous steering of the line of research. A gradual reallocation of priorities between different studied alternatives is foreseen on the basis of the results obtained in this fashion.

The cost of executing the programme is estimated to be a total of about SEK 600 million during the six-year period 1987-1992, of which about SEK 175 million is the cost of the underground research laboratory.

The R&D work is being financed with money from the funds that are built up through a special fee levied on nuclear power production. The funds are administered by the National Board for Spent Nuclear Fuel, which also disburses money to SKB.

SKB will inform the public, regulatory authorities and other concerned parties on plans, work in progress and the results of the activities occasioned by the research programme.