INTERNATIONAL COOPERATION IN THE SWEDISH NUCLEAR WASTE MANAGEMENT RESEARCH PROGRAM

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ABSTRACT

The responsibility for doing the necessary research in the nuclear waste management field in Sweden has been assigned to the Swedish Nuclear Fuel and Waste Management Co. (SKB). The present and future research is mainly related to final disposal of spent unreprocessed fuel. SKB has recently submitted a comprehensive research and development program to the pertinent authority according to the Swedish Act on Nuclear Activities. An important goal is to develop sufficient knowledge and data to be able to submit a license application for a siting permit by the year 2000. International cooperation plays a significant role in the Swedish research program. SKB has bilateral information exchange agreements with several organizations in other countries. SKB is also responsible for execution of three international projects-the OECD/NEA Stripa project, the JSS-project and the Pocos de Caldas project. These and other international programs touch on several subjects of key importance for the final disposal of high level wastes such as waste form interaction with groundwater, buffer and backfill materials, groundwater movements, radionuclide chemistry and transport etc. A common international view on the scientific bases for nuclear waste management is of great value. For a small country like Sweden, it may also be of great benefit for the long term success of the nuclear waste management program.

INTRODUCTION

The Swedish Act on Nuclear Activities (1) obligates the owners of the nuclear power plants in Sweden to jointly prepare and execute a comprehensive program for the research and development work and other measures required for the safe management and disposal of the wastes from nuclear power.

Svensk Karnbranslehantering AB-SKB (Swedish Nuclear Fuel and Waste Management Company)-has been commissioned by its owners, the Swedish nuclear power utilities, to develop, plan, design, construct and operate plants and systems for the management and disposal of spent nuclear fuel and radioactive wastes from the Swedish nuclear power plants.

SKB is also responsible for the extensive research activities within the nuclear waste field for which Swedish law makes the nuclear power producers responsible. SKB has prepared the program for research and development prescribed by the Act on Nuclear Activities. The program was submitted to the pertinent authority, i.e. the National Board for Spent Nuclear Fuel (SKN) in September 1986 (2). The program is based on the work started in 1977 by the KBS-projects and the results achieved by those projects. It has to be revised and updated every three years.

The program has now been sent for review to a large number of authorities, universities, institutes, experts and interest groups in Sweden and in other countries. The comments received from the reviewers will be compiled and evaluated by SKN, who will then report its findings and recommendations to the Swedish government by the first of June 1987.

SOME GUIDELINES FOR SWEDISH RADIOACTIVE WASTE MANAGEMENT

The R&D-program has been based on a few guidelines for the Swedish waste management program. These guidelines are not always formalized in laws or regulations, but have on several occasions been expressed in policy statements by the government and by the utilities. Some of the more important guidelines are:

- 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 fulfill high standards of safety and radiation protection and satisfy the requirements of the Swedish authorities.
- The systems shall be designed so that requirements on safeguard of fissionable material can be fulfilled.
- In all essential respects, the waste problem shall be solved by the generation that utilizes electricity produced from the nuclear power plants.
- 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 work carried out during the 1980's must not entail any final commitment to a specific site or method for final disposal of the spent nuclear fuel.

THE SWEDISH WASTE MANAGEMENT SYSTEM

The safe handling and final disposal of the wastes from nuclear power requires planning, construction and operation of a number of facilities and systems. Figure 1 shows the different parts of the planned Swedish waste management system. These parts have been described at several international meetings and also in several SKB reports (3,4,5,6,7,8). The design of the system is based on the following fundamental principles:

- Short-lived wastes will be disposed of as soon as possible after it has been generated.

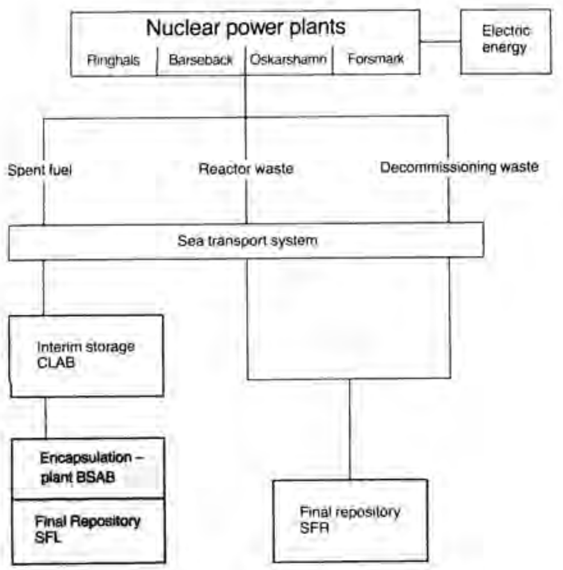

Fig. 1. The Swedish Waste Management System.

- Spent nuclear fuel will be stored for about 40 years before it is placed in a final repository. Heat generation in the final repository is thereby limited.
- Other long-lived wastes will be disposed of in connection with the final disposal of spent fuel.

Essential parts of the waste management system are already in operation or are under construction. The central interim storage facility for spent nuclear fuel, CLAB, has been in operation since 1985. The sea transport system has been in operation since 1982. The final repository for reactor waste, SFR, is under construction and scheduled for operation in 1988. It can later on be expanded to receive also the decommissioning waste.

The remaining parts for which decisions have not yet been taken are a conditioning and encapsulation plant for spent fuel (BSAB) and a final repository for spent fuel (SFL). The future R&D program will mainly be concerned with these facilities, which according to present plans will be constructed after 2010.

The wastes arising from the Swedish nuclear power program will be about:

- 7800 tons U of spent fuel
- 90000 m^3 of reactor waste
- 115000 m^3 of decommissioning waste
- 19000 m^3 of core components

and to that should be added minor quantities from R&D facilities, from hospitals and from other industry. The given quantities were calculated assuming all nuclear power plants are operated to 2010 according to the decision taken by the Swedish parliament.

An overall timetable for the measures that have to be adopted for handling and disposal of radioactive waste in Sweden is shown on Fig. 2. The timetable is not final and changes in one direction or the other may prove to be warranted. Thus, if desired, the interim storage in CLAB can be continued for more than 40 years. In practice, no commitment will be made to the choice of final disposal system for spent fuel until encapsulation of the fuel has begun. Until then the system has great flexibility to adopt new technology. It is assumed that the construction of BSAB will begin roughly at the same time as construction of SFL.

OVERALL PLAN FOR THE R&D-WORK

Figure 3 shows an overall time schedule for the R&D, technology development and other measures that are required prior to the start of construction of SFL.

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

In parallel with this, the general geological characterization of various areas that has been going on since the end of the 1990s will be completed. In the early 1990s, a couple of sites will be selected for detailed studies. These studies should not be begun later than 1993 for all sites that could be candidates for a siting application in the year 2000, which is the target date for submitting such an application for a repository for long lived wastes.

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. Thus, 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 in-situ tests should be begun in good time before the year 2000 in order to provide support for a siting application.

Larger-scale and integrated demonstration tests will probably be conducted at a later stage. The design of such tests will depend on the development of technology. Certain demonstrations and in-situ tests will probably continue 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. Their scope is, however, expected to decrease and the emphasis to shift towards phenomena of special importance for the system chosen as the main alternative.

The results from continued detailed observations on the selected site, from demonstration and in-situ tests, from supplementary basic research and from ongoing technology development will be summarized in a safety report before start of construction. This safety report should form the basis for a construction permit.

UNDERGROUND RESEARCH LABORATORY

The geological R&D work that is planned must be of high quality, have a balanced scope and be carried out effectively. These demands have been evaluated based on passed experiences such as the KBS-projects, the Stripa-project, the SFR-project and otherwise from the geohydrological studies in particular. The

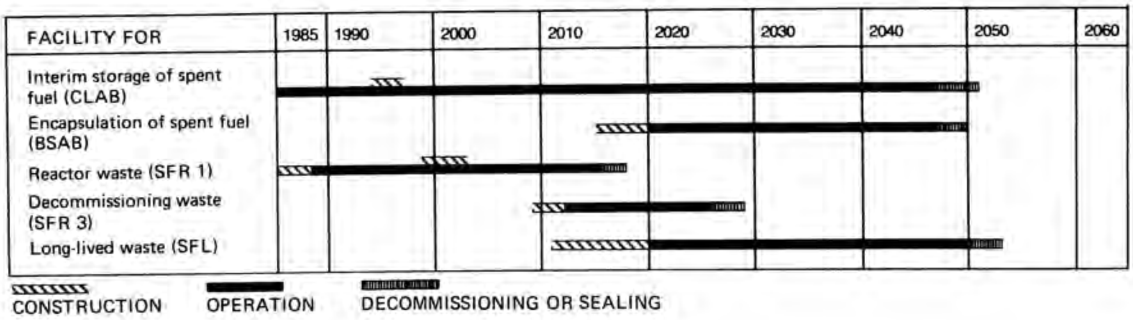

Fig. 2. Overall timetable for facilities in the Swedish Nuclear Waste Management System.

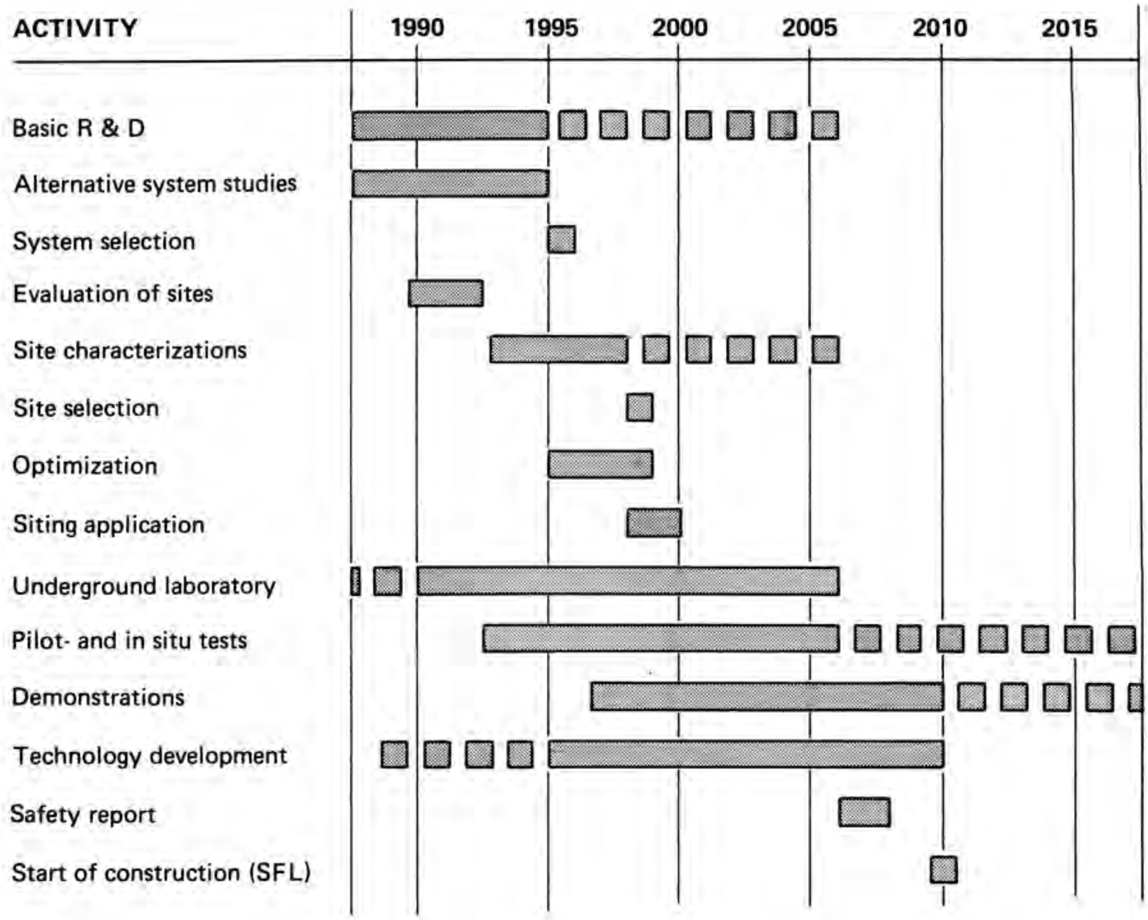

Fig. 3. Overall timetable for measures up to the start of construction of the final repository and the treatment.

evaluation clearly points to the need for more detailed and comprehensive geological investigations. The site where these are performed should have the necessary geological characteristics and be geologically undisturbed. In order to meet these and other needs indicated above, an underground research laboratory is planned. The purpose of the laboratory is to:

- Provide a base for development and testing of the detailed investigation methods that are to be used in detailed site studies during the 1990s.
- Study in detail the groundwater flow in a larger area and how this flow is affected by shaft sinking and tunnelling.
- Serve as a site for geoscientific investigations and experiments including nuclide transport (with groundwater).
- Provide a site for pilot tests with components, equipment, civil engineering methods or construction technology.
- Provide a site for in-situ tests and large-scale demonstrations.
- Serve as a well-characterized reference site for studies of difference repository design alternatives.

The underground laboratory should be available in the early 1990s when the present Stripa project will be completed. This means that the preinvestigation work has already started. To begin with, we are investigating the suitability of the area at the Oskarshamn nuclear power plant on the south-eastern coast of Sweden. If the conditions prove suitable, the site for the research laboratory may be one of the sites chosen for detailed investigations in the repository site selection process. The experience gained from the establishment of the underground research laboratory will be of great importance in the choice of sites for detailed investigations.

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. Sweden and SKB is involved in this work in many ways. In fact international cooperation plays a significant role in the R&D program-86, which has been very briefly described above.

SKB has formed bilateral agreements on information exchange with the following organizations in other countries:

Canada	AECL
France	CEA
Switzerland	NAGRA
USA	DOE
CEC	Euratom

Besides those formal agreements, SKB has also informal contacts with several other organizations in countries such as Belgium, Finland, Japan, Spain, West Germany and UK.

SKB is the executive organization for three international research projects-the OECD/NEA Stripa Project, the JSS project and the Pocos de Caldas project. SKB participates in the URL-project in Canada and in the international HYDROCOIN project headed by the Swedish Nuclear power inspectorate.

The following paragraphs summarizes how these projects and other international comparative arrangements fit into SKBs R&D program. The headlines refer to the various main components in an underground multibarrier repository system in granitic bedrock.

WASTE FORM

The waste form for high level wastes in the Swedish program is spent nuclear fuel. Some studies on vitrified high level waste from reprocessing is, however, still going on. The JSS-project is a joint Japanese-Swiss-Swedish project for studies of radioactive glass. The original goals of the project were to:

- Determine whether radioactive glass displays different behavior in any respect on contact with water than a chemically identical non-radioactive glass.
- Build-up an independent database for the glass that was to be delivered in the future from COGEMA in France under existing reprocessing agreements.

These investigations were carried out in 1982-1985 and their results are reported in Ref. 9. The data obtained were of such good quality that they have been deemed suitable to serve as a basis for development of a predictive model for glass leaching under repository conditions. This is the goal of phases IV and V of the project which are carried out during 1984-1987. Preliminary results show that the model development is very promising (10). A few results are given in Fig. 4.

The studies of spent fuel are still in a more fundamental stage than the studies of high level waste glass. Leach experiments have been carried out on spent fuel for a number of years; in Sweden mainly on BWR-fuel, in the US on PWR-fuel have started recently. In order to provide a forum for a regular informal exchange of experience and ideas, a workshop on spent fuel leaching is organized annually. Sweden, Canada and the USA take turns hosting the workshop, but representatives of all laboratories working actively with leaching/corrosion of spent UO_2-fuel participate. By this type of information exchange, one gets a broader database that provides the necessary background

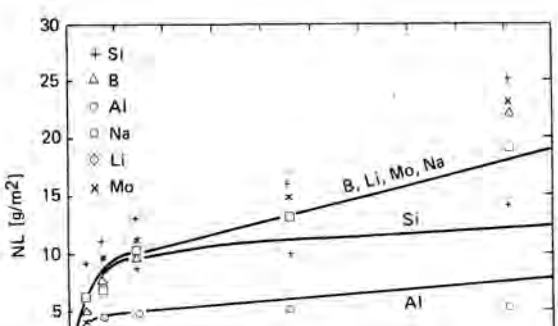

Fig. 4. Comparison between leaching results (points) from radioactive glass in deionized water (static test, temp. 90^{0}C, glass area/liquid volume=10m^{-1}) and model calculations (curves). NL=Normalized mass loss for the element in question.

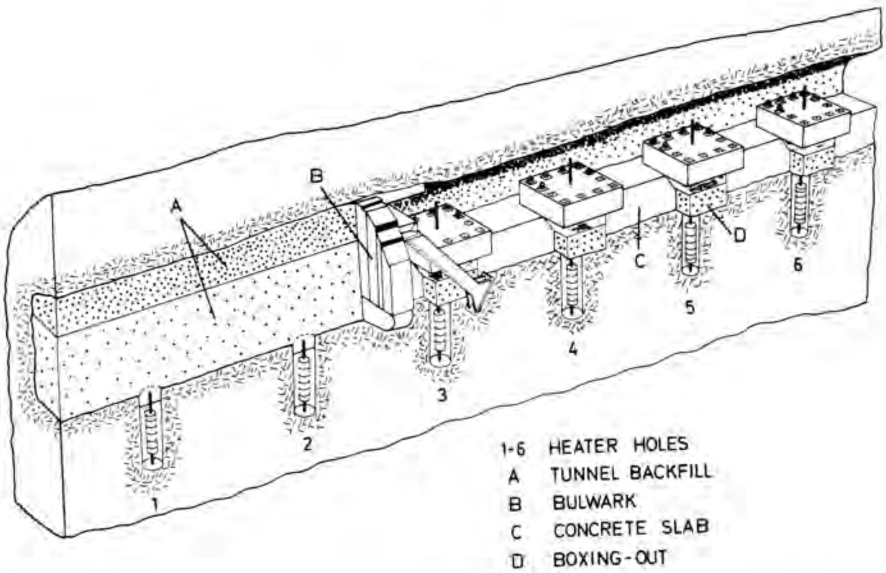

Fig. 5. View of the Stripa Buffer Mass Test.

material for starting the work on a more fundamental theoretical understanding and description of the leaching process.

The goal of SKBs continued studies of spent fuel behavior in a repository chemical environment is to gain sufficient knowledge of the mechanisms and kinetics of the dissolution of UO_2-fuel to develop a predictive model that can be used as a source term in safety assessments. We feel that this goal is still some years away, but we also think that the model development work within the JSS-project and the discussions and information exchanges at the spent fuel workshops will help us a great deal on the way to that goal.

BUFFER, BACKFILLING AND SEALING MATERIALS

Buffer in deposition holes and backfill in rock caverns, tunnels and shafts are examples of engineered barriers in a final repository system. The primary function of these barriers is to prevent or limit groundwater flow and to create a chemical and mechanical protection zone around the waste package.

Sealing measures can be adopted in rock caverns in the form of plugs or in the host rock in the form of injection grouting.

The reference materials for buffer and backfilling in the Swedish studies has so far been bentonite, highly compacted bentonite and mixtures of sand and bentonite. Future studies will cover also alternative materials.

Highly compacted bentonite as a buffer in deposition holes and bentonite/sand mixtures as tunnel backfilling have been tested under several years in the Buffer Mass Test as part of the Stripa project (see Fig. 5). The test was made under realistic rock conditions at 360 m depth in granite on a half-size geometric scale. The temperatures were up to about 80°C during water uptake and up to 125°C at water-saturated conditions. The results have confirmed previous laboratory experiments and theoretical calculations (11).

Furthermore, within the Stripa project, highly compacted bentonite has been tested as a sealing material in plugs in boreholes, shafts and tunnels. The results show that the material is practical to use and very effective for watertight filling of limited spaces in rock with hydraulically conductive fractures (12).

The third phase of the Stripa project which has started during the summer 1986 and will continue for five years includes an extensive research effort on materials for injection grouting in fractured rock. Properties of various materials will be studied. A large-scale grouting test is planned for the latter part of the project. Of particular interest is to find and evaluate materials with long-term stability in the expected repository environment.

The properties of clay materials for buffer and backfill is also studied in cooperation with CEA, France. These studies supplements and expands the domestic Swedish and the Stripa project studies.

GROUNDWATER MOVEMENTS

Knowledge of groundwater movements in the bedrock is very important for the safety assessment for the final repository. The models used so far in this field are simplified and based on limited data. For this reason, very cautious and pessimistic assumptions have been made in the safety analyses. Several research projects are, however, under way which will substantially broaden the database and enhance the understanding of groundwater flow in crystalline rock.

The international Stripa project includes extensive geohydrological work aimed at development of methods. The research so far has shown that a series of different types of investigations and measurements are required in order to be able to determine the extent and location of the planes of weakness in the rock. Several geohydrological and geophysical techniques have been successfully developed and tested in phases 1 and 2 of the Stripa Project. An extensive program of water sampling has also been carried out within the hydrogeochemical part of the project. The results so far show that deep granitic groundwaters can have very long residence times. The hydrogeochemical research has also contributed to new knowledge of the chemical character and origin of the groundwater in granite (13).

The future work at Stripa-phase 3 (of the international Stripa Project-is aimed at applying the experiences gained in the previous phases and from other research to an undisturbed granitic rock volume. A rock mass of about 125 m x 125 m x 50 m (see Fig. 6) will be investigated in detail. A mathematical model will be developed and the results from modelling will be compared with measured data. The mathematical model to be tested is based on a combined deterministic and statistical description of the groundwater flow in a discrete fracture pattern in three dimensions. Other groups will test different models in conjunction with the Stripa Project. The work at Stripa also includes a comprehensive program of tracer tests aimed at studying the channelling phenomenon for the flow of groundwater in fractures.

SKB has decided to join the Canadian URL-project (URL=Underground Research Laboratory) at Whiteshell in Manitoba. This project includes an extensive geohydrological characterization and modelling of the area at URL and also a shaft sinking to 450 m depth.

Ongoing field investigations in Sweden of importance for the understanding of groundwater movements are in particular the "Fracture Zone Project" initiated in 1984 by SKB. Two different fracture zones (at Finnsjön and at Avrö) are being studied in great detail including various geohydrological and geophysical techniques and also tracer tests. Furthermore, data are being collected from a number of ongoing tunnel projects that intersect various types of fracture zones. The "Fracture Zone Project" in its currently planned scope is expected to be completed by 1989. Another important domestic project that provides extensive geohydrological data and experience is the construction (and in the future operation) of the SFR-low and medium level waste repository.

The various projects indicated above will together give us the experience and knowledge needed for detailed site characterization of potential sites for a deep repository. In summary:

- The Stripa Project is aimed at studying a rock mass of relatively good rock on a scale about 50-150 m diam.,
- The Fracture Zone Project is aimed at studying properties of various fracture zones,
- the construction of the new Underground Research Laboratory (in Sweden) is aimed at studying a larger rock volume (scale 500-1000 m diam.),
- the SFR-project and the Canadian URL-project supplement these field investigation.

In conjunction with all the above mentioned projects, there is a continuous ongoing development of mathematical models for groundwater flow. The international HYDROCOIN-project plays a key role in comparing and verifying the computer codes implementing these models. The HYDROCOIN project started in 1981 and is planned to be completed in 1987. A follow up project called INTRAVAL is currently in planning. These projects are handled by the Swedish Nuclear Power Inspectorate (14).

RADIONUCLIDE CHEMISTRY AND CHEMICAL TRANSPORT

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, at least as important for safety as the groundwater movements. Only a few projects in this field will be mentioned as examples of ongoing activities.

Field studies of how sorbing and non-sorbing tracers are transported with groundwater have been

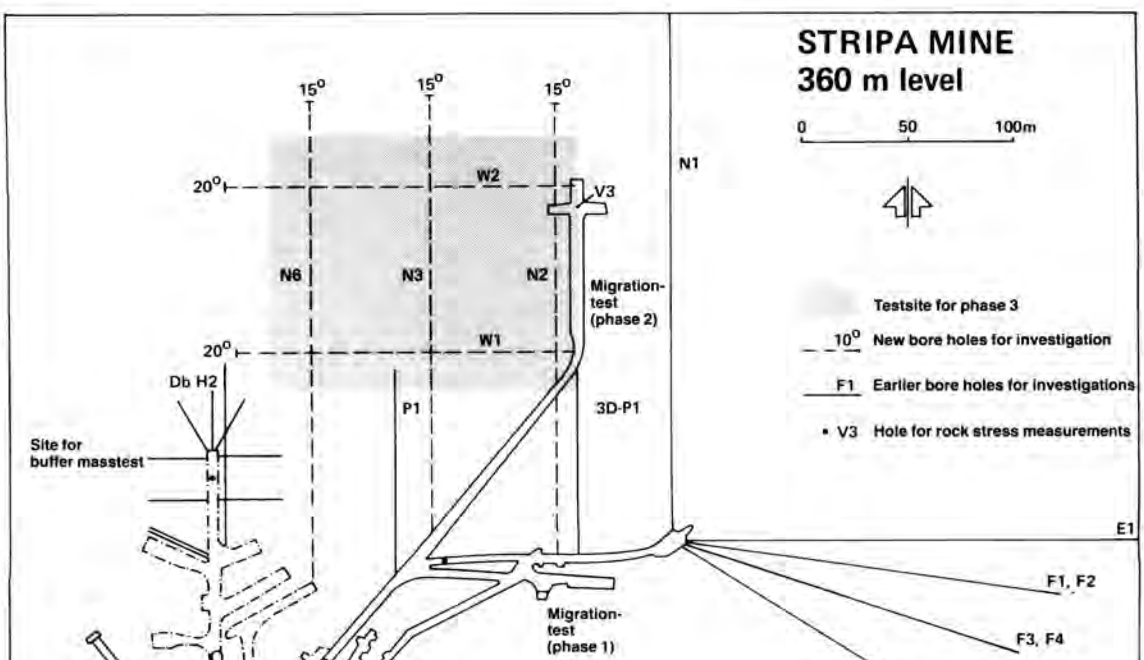

Fig. 6. Schematic illustration showing the test site for the planned geohydrological investigations in Stripa phase 3.

conducted and are being conducted within the Stripa Project. Further tests are planned both at Stripa and within the "Fracture Zone Project" and later at the underground research laboratory.

Tests being conducted in the field and in the laboratory can, for natural reasons, only be performed on a relatively short time scale. The results can, therefore, not be used to validate calculational models for radionuclide transport on the longer time scale that is relevant for a final repository. In order to obtain data that are representative for this longer time scale, so-called "natural analogues" are studied. These include the transport of naturally occurring radioactive materials such as uranium and thorium and their decay products. SKB is participating together with NAGRA in Switzerland and the Department of Environment in Great Britain (UKDOE) in a study of a uranium mineralization and a thorium mineralization at Pocos de Caldas in Brazil. Recently also the Department of Energy in USA (USDOE) have decided to join the Pocos de Caldas project. This started in 1986 and is planned to extend over a three-year period. The project deals with the following aims:

1) Determination of speciation and chemical transport of natural radionuclides and rare-earth metals in a fracture flow system in crystalline rock under oxidizing and reducing chemical conditions. This will be studied at the Osamu Utsumi C-09 uranium mine, an important open pit mine. The conditions for studying redox transitions in connection with fracture-bound water flow are the best imaginable.

2) Formation and mobility of colloid-borne radionuclides in natural groundwater. This will be done at Moro do Ferro a large and very rich thorium deposit in Brazil.

SAFETY ASSESSMENT

The very long time periods, during which highly radioactive waste constitutes a potential hazard to man, puts the safety assessment for a repository right in the middle of the international interest. Consequently, there is an ongoing multinational cooperation in many areas related to radiation safety. Many international organizations are involved in this work e.g. IAEA, ICRP and OECD/NEA. Sweden is actively participating both through authorities and through SKB. The focus of the work is at present on:

- methods and praxis in handling uncertainties and variability in safety assessments,
- development and comparison of probabilistic performance assessment models,
- selection and analysis of scenarios in safety assessments,
- establishment of international quality assured databases,
- exchange of plans and information on the use of natural analogues for the validation of processes of importance for the long term safety.

SKB actively supports work in all these areas. International consensus on the means and methods for safety evaluation and a common basis for safety goals is an important factor in scientific, public and political acceptance on disposal methods.

CONCLUDING REMARKS

For a small country like Sweden, international cooperation plays an important role for the long term success of the nuclear waste management program. The benefit that can be derived from research in other countries and from international projects lies on several different planes:

- Contributions to method and model development.
- Broadened and strengthened databases.
- Exploration of different alternatives for repository and/or barrier design, material choice, etc.
- Establishment of an internationally recognized base of scenarios, methods and data for repository safety assessments.
- Contribution to strengthen public confidence in and acceptance of the system chosen.

This paper gives a very brief review of some of the international cooperation which SKB has engaged in and also tries to put these projects into context with our overall R&D program. We feel that so far our international programs have been reasonably successful and effective to produce valuable results not only for SKB and Sweden, but also for other participants. To get full benefit from international cooperation, it is, however, necessary to engage your staff and allocate enough time and resources. It is also important to find a good working organization for the specific project.

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