DIRECT DISPOSAL OF SPENT NUCLEAR FUEL - KEY RESEARCH AREAS

P.-E. Ahlstrom, T. Papp
Swedish Nuclear Fuel and Waste Management Co.

ABSTRACT

The Swedish plans for nuclear waste management forsee a final repository deep in the bedrock to be operational by the year 2020. To achieve this, a site selection and a selection of a site specific optimized repository system should be made during the 1990's, and an application for a siting license be made before the year 2000. After the feasibility of a safe final disposal of spent nuclear fuel was accepted by the Swedish Government in 1984, the aim of the R&D program is to develop a safe and efficient repository based on a broad evaluation of available alternative designs.

BACKGROUND

After an advisory referendum in 1980 on the future use of nuclear energy in Sweden, the Parliament decided that all nuclear reactors were going to be taken out of the system by the year 2010 at the latest. In 1985 the two last reactors in the Swedish twelve reactor nuclear program were taken into operation. Thereby, the nuclear generating capacity is 9,500 MW. The nuclear system produces today almost half of the total electric energy produced per year in Sweden.

In the Swedish legislation on nuclear waste, two main points are made:

- The fueling of a new reactor is only allowed if the feasibility of a safe disposal of the waste is shown;

- it is the producer of the nuclear waste who is primarily responsible for the safe handling and final storage of it.

The main strategy for waste management in Sweden is based on the direct disposal of spent fuel without prior reprocessing. All costs for the management of the nuclear wastes have to be carried by a fee on the electricity produced by the reactors. The fee for 1986 is 0.019 SEK per KWh and it is collected in a fund.

The Organizational Framework

The Swedish Nuclear Fuel and Waste Management Company, SKB, owned by the Swedish nuclear utilities, has been assigned to manage all the nuclear waste outside the power stations. The handling of waste and the facilities needed are supervised by the Nuclear Power Inspectorate (SKI) and the National Radiation Protection Institute (SSI) see Fig. 1. The R&D work is supervised by a special authority, the National Board for Spent Nuclear Fuel, SKN.

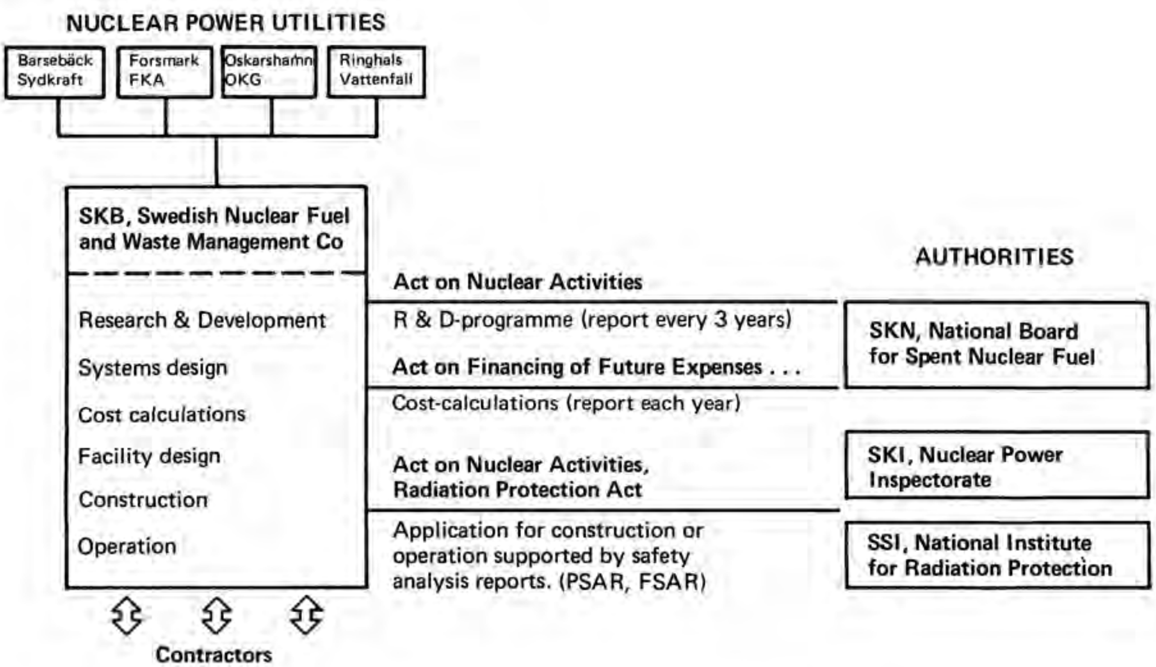


Fig. 1. Radioactive Waste Management in Sweden.

All the authorities have their own research budgets. In the nuclear waste area, their research is focused on safety questions and acceptability criteria.

In compliance with the intentions of the legislation, the responsibilities of SKB include:

- The planning and cost calculations for the total nuclear waste management system (except handling and treatment at the reactor sites);
- the design, construction and operation of all necessary facilities for storage and disposal of nuclear wastes;
- all transportation and conditioning of the spent nuclear fuel and other radioactive wastes outside the reactor sites;
- all the research and development work necessary to achieve an acceptable safety for the total management of the waste.

SKB is organized in three main divisions, see Fig. 2. The main task for the division for planning and systems analysis in the waste field is to plan for the total management system and to provide cost calculations for it. These calculations are updated every year and delivered to SKN, where they constitute a part of the basis for the fee that the government on recommendations from SKN will set on nuclear power.

The division for facilities is responsible for the design and construction of the required systems or facilities as well as the operation of them after they have got the operating licenses. The main activities at present are the operation of the Clab facility for interim storage of spent nuclear fuel, the operation of the sea transport system between the nuclear sites and the Clab and the construction of SFR, a final repository for low and medium level wastes from reactor operations.

The task for the research and development division is to initiate, plan and coordinate the research and development needed to achieve a safe waste management in Sweden. The annual research budget is 70 MSEK (abt 9 million USD). It is required in the law that the status of the research and development, and the plans for the coming six years are presented to SKN every third year.

The Present Situation

The main goal for the R&D made by SKB before 1984 was to get fueling permits for the six last reactors in the Swedish program. This was achieved by two reports presenting the concepts for final disposal of vitrified high-level waste from reprocessing (KBS-1 in 1977) and for the direct disposal for nuclear fuel without reprocessing (KBS-3 in 1983). The evidence presented on the feasibility of safe final storage was accepted by the government after a detailed scrutiny of the reports by domestic and foreign reviewers. The acceptance of KBS-3 in 1984 ended the feasibility phase of the R&D program, and started the optimization phase. As a result of the feasibility studies, a number of conclusions could be drawn:

- The Swedish bedrock is stable enough to provide a predictable geophysical environment for a repository over millions of years;
- already with the technology of today, we can surround the radioactive waste with man-made barriers of long service life to isolate the waste from the groundwater, to limit the rate of interaction between the repository and the flowing groundwater, and to limit the rate of dissolution of the radionuclides from the waste matrix;
- safety evaluations show that combinations of natural and man-made barriers can be designed to such a quality that the radiological impact on man will be insignificant, compared to the natural background radiation in Sweden.

The safety evaluations of the concepts are based on a number of pessimistic assumptions. Less well known phenomena or factors that are beneficial are not taken credit for. Methods and data are generally selected in a way to give an upper limit for the consequences. The repository concept can thus be regarded as overly-safe in the sense that substantial but not quantifiable safety margins are incorporated in the assessments. An appropriate research and development effort is expected to permit simplications of the system and cost reductions through:

- optimization of the repository;
- greater flexibility in site selection;
- quantifications of safety margins.

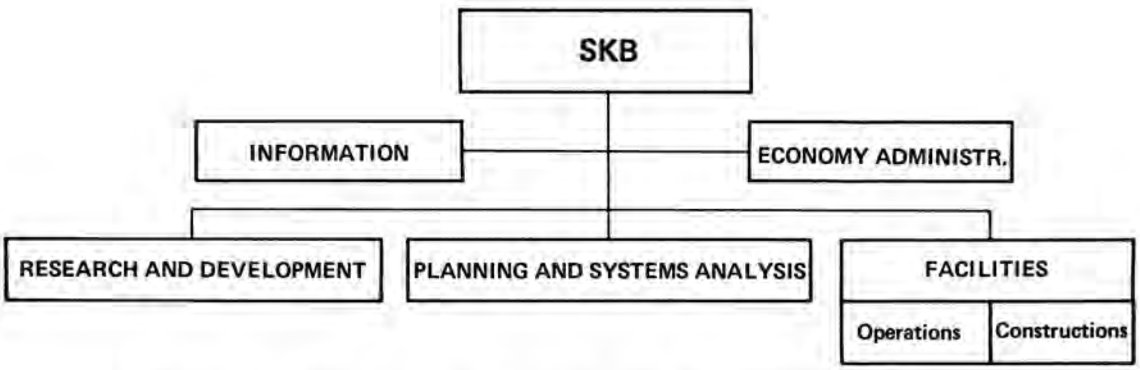


Fig. 2. Organization of the Swedish Nuclear Fuel and Waste Management Co. SKB.

Future Research and Development Plans

The goal for the research and development effort is to provide support for a stepwise site selection process, a screening of alternative ways to provide man-made barriers around the repository and the selection of a site specific and optimal repository design. This will also include the development of necessary methodology and probabilistic models as tools for the performance and safety evaluations.

The basis for the planning is the overall timetable for taking a final repository for spent fuel in operation, Fig. 3. This timetable is based on forty years interim storage of spent fuel in Clab. Construction of the final repository is planned to start about 2010. The time available until then will be used for R&D work, optimization and design, site investigations and site selection. License application for a repository is planned to around year 2000.

Based on legal requirements and specific Swedish conditions, the framework for the development of a final repository for spent nuclear fuel is as follows:

- In the Swedish nuclear energy program, the present twelve reactors will be operated to year 2010;
- the R&D shall focus on the disposal of spent nuclear fuel as such with no reprocessing foreseen;
- the final disposal will be made in a common type of bedrock in Sweden;
- the final disposal shall be made in a way giving an acceptable safety to the society and with reasonable efficiency and economy;
- the longterm safety of the repository system shall not depend on possible human intervention or remedial actions;
- the longterm safety of the repository shall not be jeopardized by deficiencies in one of the safety barriers of the system.

To optimize the total cost for achieving an acceptable safety level in any specific repository, a high degree of technical flexibility is needed both in barrier design and in siting, e.g., to be able to site repositories in bedrock with less stringent requirements for low groundwater flow. A further evaluation of the research areas given below are of importance for the realization of the final repository in Swedish bedrock:

- The stability of the host rock;

  The general stability of the fennoscandian shield and the long-time aspects. Where do movements occur and what parts are stable. How will the repository affect its surroundings?

- The groundwater chemistry and its interaction with the repository;

  The waste matrix dissolution (data and modelling). The near-field speciation and interaction. Alternative canister materials and canister corrosion. Nuclide transport and retention. Temperatures.

- Methods to isolate the waste or to reduce its interaction with groundwater;

  Alternatives to canister materials, buffer and backfill materials. Their long-time stability. Temperatures. Reduction of groundwater flow by reducing the permeability or by creating preferential groundwater pathways.

- Site comparison and site selection;

  The relative importance of the rock types, repository depth, surface topography, fissure zone geometry, hydraulic conductivity, water chemistry, etc.,

- Practical handling methods;

  Waste conditioning, canister production and deposition methods. Backfilling and sealing.

- Radionuclide dispersion in the biosphere and effects on man;

  Natural variability with time, acceptability criteria with regard to future climate and to ecological or evolutionary change.

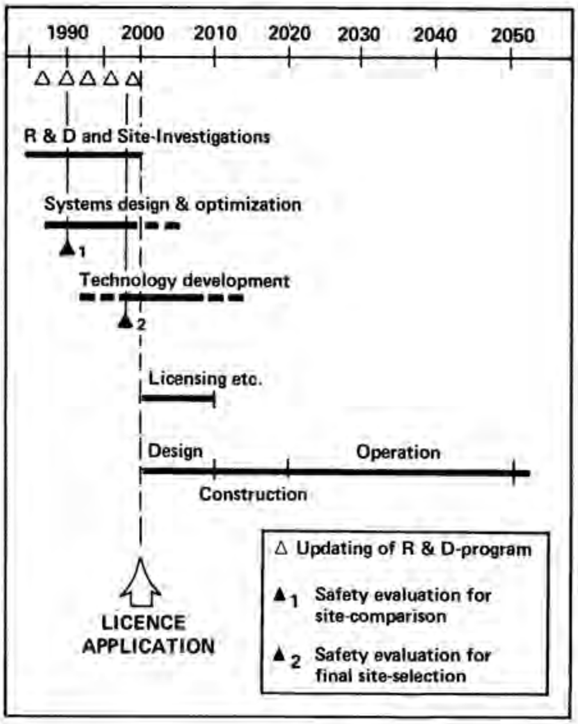


Fig. 3. General time-table for a final repository for spent nuclear fuel.

In all these areas, both the data base and the models will have to be further developed with a special emphasis on validation through experiments and naturally existing analogue systems.

Important areas for technical development will be instruments for geophysical and geochemical measurements, techniques for making or applying barriers around the waste and techniques for the control of the quality of them. Methods and models have to be developed for the probabilistic evaluation of the performance of the barriers of the total system.

The focus of the research will vary with time due to the general goals of the R&D plan in Fig. 3. A somewhat more detailed plan for the period 1986 to 2000 is given in Fig. 4. The timetable is focusing on three evaluation phases. The first is 1990, when a few sites will be selected for detailed site investigations. On at least one of them, a shaft will be made down to about 500 meters for high resolution measurements and mapping of the bedrock.

The second evaluation phase will come around 1993 when enough information on construction and long time function of alternative barriers is expected to be available to allow selection of the repository system.

The third evaluation phase will be around 1998 when a preliminary safety report will be produced as support for the siting application.

The R&D work during the 1980's will focus on the data necessary for the site-screening and the constraints various alternative barriers can have on the site.

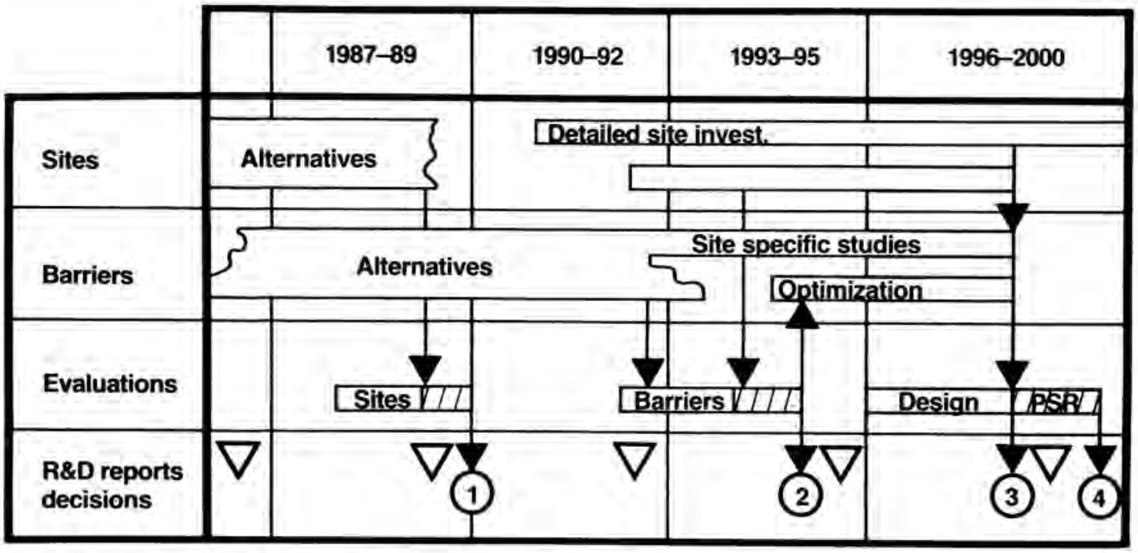
The selection of the sites for further investigations will allow reevaluation of the priorities, particularly for the research on the geology and chemistry. There might also be some alternative designs that can be discarded.

The design and barrier oriented research will focus on data and knowledge needed for the comparison of the alternatives. The work might result in requirements for large scale, long-time tests or in situ experiments to demonstrate the function or to achieve public acceptance.

After 1993, a new reevaluation of research priorities is possible, now focusing on one or two sites and at most a few alternative repository concepts. In the middle of the 1990's enough data should be available to start a site specific design for the repository including detailed dimensioning and optimization. This work will end with the production of a PSR (Preliminary Safety Report) and the application for a siting permit. The plan for development of the methodology for evaluations, the assessment models and the data bases will be adapted to the need for various types of evaluations needed in the above mentioned phases.

For the three year period from 1987 to 1989 this means that:

- The ongoing site investigation will be completed. Among the investigated areas, all interesting rock types must be included as well as sites interesting from other reasons than pure geological;
- models and methods for systematic evaluations will be further developed to a point where meaningful site comparisons are possible. This requires special development efforts for models describing groundwater movements in fissured crystalline rock;
- an evaluation of possible alternative methods for providing man-made safety barriers around the wastes will be initiated;



1 Selection of a few sites for detailed investigations 1990

2 Selection of the barrier system 1993/4

3 Selection of preferred site 1998

4 Application for siting licence based on preliminary safety report 2000

Fig. 4. The SKB time schedule for site and system selection.

- possible designs of the repository layout will be studied to screen options for adapting barrier configurations to available sites;

- programs, methods and instruments will be developed for the next phase-the detailed site investigations.

Spent fuel, groundwater and crystalline rock are components in all conceivable Swedish repository concepts. The research and development program must continue the studies of these elements and their interactions with each other and the environment. The required level of understanding of a process must be evaluated on the basis of how important the process is for the safety and of how uncertainties in the data or modelling will affect the environment consequences.

In some areas, it will be necessary to accept that the modelling and evaluation of a process can not be complete. Here the uncertainty must be compensated by appropriately selected unfavorable data or the application of safety margins.

Some Key Research Areas

Based on the research goals and priorities given earlier, a number of key research areas can be identified. Here some of them will be highlighted.

Spent fuel dissolution

Since the spent fuel constitute the source for radionuclides in the repository, the release rate of the nuclides are fundamental to the safety of the repository. It is considered necessary to further characterize the fuel matrix and the release of nuclides from it including the identification of possible solubility limiting secondary solid uranium-phases. Solubility constraints in site-specific groundwaters might be one of many possible discriminating factors in site selection. With regard to data collected during five years, solubility experiments in Sweden and in other countries and the thermodynamical data base for uranium under development for NEA Data Bank in Paris, we now consider it is meaningful to make an attempt to model the dissolution of spent fuel based on the dissolution mechanism, the kinetics and the solubility constants.

Near field

Many release limiting barriers are situated in the near field around the waste. When a major effort is made to identify possible alternative ways to create barriers, the effect of them on the total near-fields stability must be investigated in detail. Of special interest for us are the temperatures, the redox-front and possible actinide coprecipitation with uranium.

The long-time spans involved will require that experimental data are supplemented with validations by naturally occuring analog systems.

Use of standard construction materials

The need for predictions over long times is reflected in most repository concepts. Efforts are often made not to disturb the natural environment and materials are often selected in a way to permit the proof of their stability with the aid of geological evidence.

However, the use of standard construction materials in the repository might simplify the construction and reduce the cost. During the coming phase of evaluating alternative materials, special efforts will be made to investigate the possibilities of using e.g.,concrete in the buffer or backfill or cement for grouting purpose in the nearby rock.

There are many indications that the high pH environment caused by concrete would reduce the solubility of many important radionuclides. The long-time stability of the concrete is, however, not evaluated, nor is the effect that the plume of high pH downstream the repository might have on Kd and nuclide retention.

Hydrogeology

The earlier Swedish work in this area has been focused on the high quality, low permeability rock between fault zones. There are, however, reasons to believe that also the more fissured and fractured zones can constitute high capacity barriers against the migration. In order to be able to account for this in the safety assessments, a several-year project is planned on "flow and nuclide migration in fracture zones in crystalline rock".

There are also man-made features that might influence the groundwater flow around the repository. It is possible to create a "hydraulic cage" to establish preferential flowpaths around the waste and/or to grout water-bearing fissures to lower the hydraulic conductivity close to the waste. The long-time effects of these methods should be evaluated.

Biosphere

From the stability point of view, the biosphere is belonging to a special class. Not only is it exhibiting substantial regional and local variations, it is also affected by changes that can occur over time periods that are short compared with the expected duration of possible releases from the repository. These changes occur on different time scales.

- over 100 years substantial changes can occur in the groundwater recipients due to eutrophication of lakes, change of groundwater level, etc.

- over 10 000 years substantial climatic changes are expected to occur such as a global temperature rise or regional glaciations

- over one million years evolutionary changes like the establishment of new species might occur, including possible changes in man

This situation causes an unavoidable uncertainty in the consequence estimations and will reduce the meaningfullness of a simple application of the biosphere transfer factors of today.

An effort will be made to look especially on the changes that have occured since the last glaciation about 10 000 years ago to identify the span of biosphere variation and to identify its importance to the safety. To be able to get a reasonable long-time perspective and to compare safety evaluations made by different groups in the world, there is also a need for an international consensus on how these uncertainties should be handled.

CONCLUDING REMARKS

The Swedish research on the final storage of radioactive waste is presenting changing its focus from a feasibility oriented program into a phase where finally the actual site and repository system must be defined. The selection of the site and the barrier system will be done in a stepwise process starting with the evaluation of a number of alternative sites and man-made barriers. In the middle of the 1990's, a site specific design optimization is expected to start ending in the preliminary assessment of environmental impact and safety. This report will be the basis for an application to Government for a siting permit close to the year 2000.

BIBLIOGRAPHY

KBS-1: Handling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Reprocessing Waste, The Swedish Nuclear Fuel Safety Project (KBS), November 1977, Stockholm, Sweden

KBS-3: Final Storage of Spent Nuclear Fuel-KBS-3, The Swedish Nuclear Fuel Supply Company, May 1983, Stockholm, Sweden

An overview of the repository system for spent fuel is given in:
Nilsson, L. B., C. Thegerstrom. The Swedish KBS-3 Concept and Program for Continued R&D Work. Waste Management-84, Volume 1.