RADIOACTIVE WASTE MANAGEMENT IN SWEDEN EXPERIENCES AND PLANS

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Abstract

Since some years, the necessary facilities are in operation in Sweden for the safe transport and storage of radioactive waste and spent fuel from nuclear power production. These include a final repository, SFR, for short-lived low and intermediate level waste, a central interim storage facility, CLAB, for spent fuel and a sea-based transport system. The experiences from the operation of these facilities have generally been very good. The next step is the development of an encapsulation facility and a deep repository for the spent nuclear fuel. R&D-work on direct disposal have been conducted in Sweden for more than 20 years. In the preferred method the spent fuel will be encapsulated in a copper canister with a steel internal structure, and the canister will then be disposed of at about 500 metres depth in the Swedish bedrock. The siting and design of the encapsulation facility and the deep repository is now in progress.

1. INTRODUCTION

About 50 % of the electricity in Sweden is generated by means of nuclear power from 12 reactors located at four sites (see Fig. 1) and with a total capacity of 10,000 MW. Nine of the reactors are BWRs and three PWRs. The first commercial reactor was put in operation in 1972 and the latest in 1985. Discussions about closing the first reactor for political reasons is going on in Sweden. If all reactors are operated until 2010, about 8,000 tonnes of fuel will have been generated and will have to be taken care of as spent nuclear fuel. Today, about 3,700 tonnes have been generated.

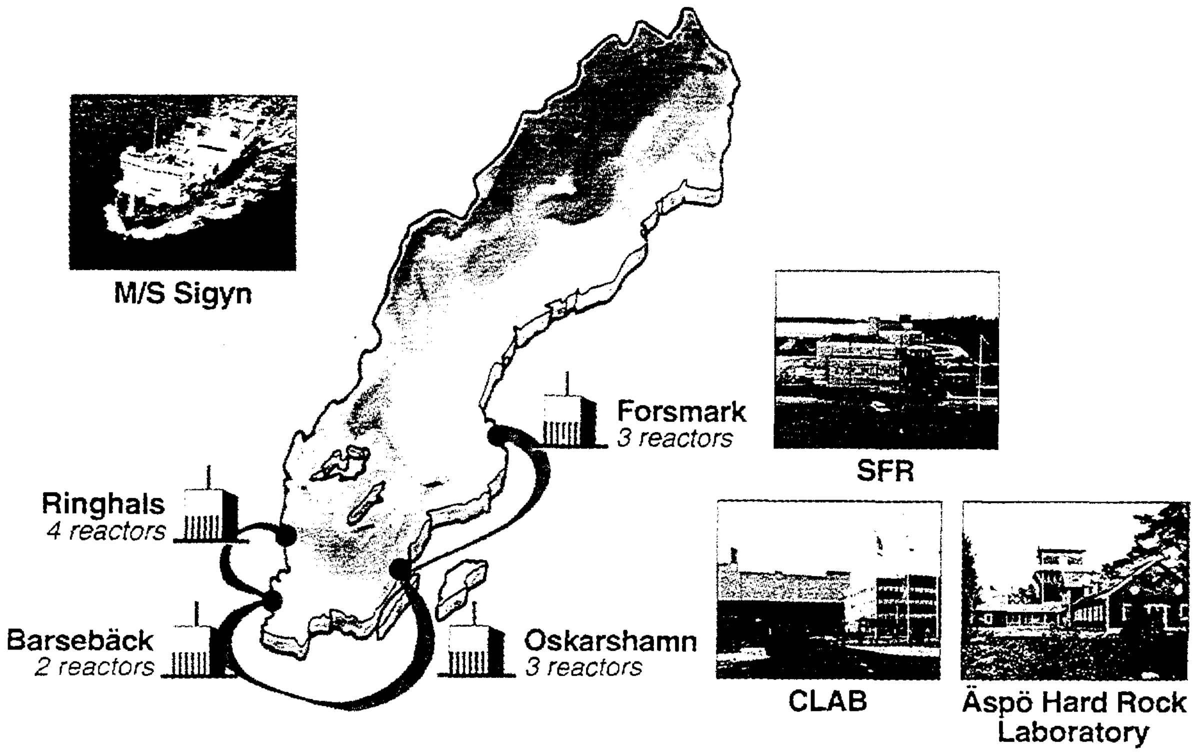

FIG. 1. Location of the Swedish nuclear power plants and nuclear facilities

The responsibility for the management of the spent nuclear fuel, as well as for other radioactive residues from nuclear power production, lies with the operators of the nuclear power plants, i.e. the four nuclear utilities. The utilities have jointly created SKB, the Swedish Nuclear Fuel and Waste Management Company, to safely manage the spent fuel and radioactive waste from the reactors to final disposal. The task of SKB is thus to plan, construct, own and operate the systems and facilities necessary for transportation, interim storage and final disposal.

SKB has developed a system that ensures the safe handling of all kinds of radioactive waste from the Swedish nuclear power plants for a long time period ahead. The keystones of this system are (Fig. 2):

- A transport system which has been in operation since 1983;
- A central interim storage facility for spent nuclear fuel, CLAB, in operation since 1985;
- A final repository for short-lived, low and intermediate level waste, SFR, in operation since 1988.

The remaining components of the system that are now being planned are:

- An encapsulation facility for spent nuclear fuel; and
- A deep disposal facility for encapsulated spent fuel and other long-lived radioactive wastes.

The costs for the management of all radioactive residues from the nuclear power plants, as well as for the decommissioning of the plants is borne by the operators of the reactors. To cover all future costs and ensure that means will be available, a fee is levied on nuclear electricity. The fee is about 0.015 SEK/kW·h (about 2.0 US mills/kW·h) and is paid to the state and is used for the activities of SKB.

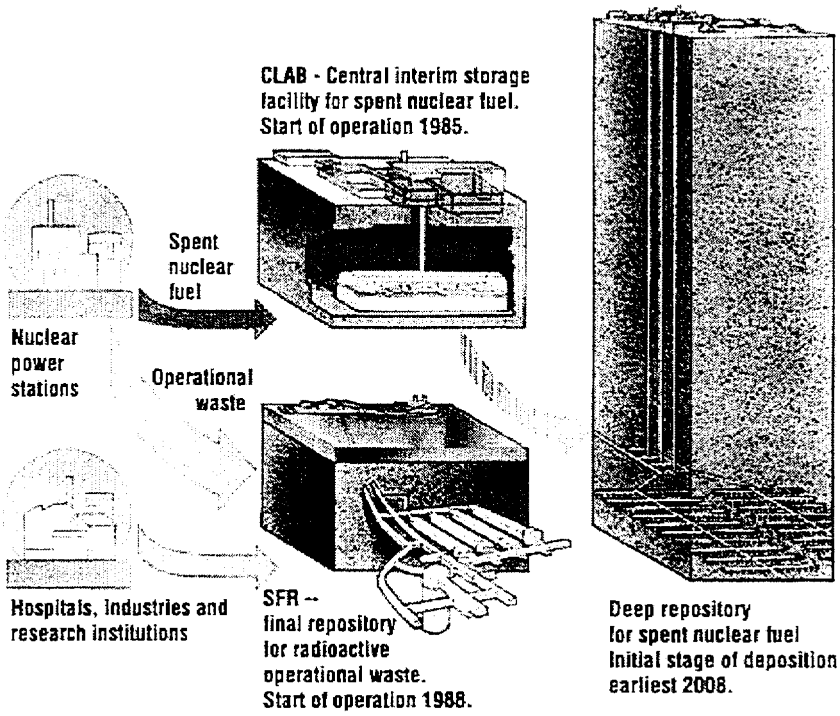

FIG. 2. The Swedish waste management system

2. SWEDISH FINAL REPOSITORY FOR RADIOACTIVE WASTE (SFR)

SFR, the Swedish Final Repository for Radioactive Waste, is a central disposal facility for all short-lived low and intermediate level waste from the operation of the nuclear power plants. SFR is located close to the Forsmark nuclear power plant on the east coast of Sweden. The storage capacity of SFR is at present 60,000 m^3. Later, it will be extended to accommodate also the waste from the decommissioning of the nuclear power plants. Similar waste from the use of radioisotopes in medicine, research and industry will also be disposed of in the SFR.

2.1. Repository design

The SFR is built in bedrock at about 50 meters depth. It is built underneath the sea-bottom about one kilometer off shore from the harbour at Forsmark. The repository has been designed so that the waste will be isolated to prevent any escape of toxic components into the environment in harmful quantities even after the facility has been sealed and abandoned. No institutional control is foreseen after sealing. The isolation is accomplished by different barriers surrounding the waste.

In the SFR, the waste is disposed of in different rock caverns (Fig. 3), that have been adopted to the different waste types and their different demands on handling and barriers [1]. The most active waste is disposed of in a concrete silo built in a cylindrical rock cavern. The silo is about 50 m high and has a diameter of 25 m. The thickness of the concrete wall is about 0.8 m. The waste is deposited in the silo by remote handling and successively surrounded by concrete grout. In between the silo wall and the rock bentonite clay is placed, which after closure of the facility will ensure that the nuclide transport is governed by diffusion, i.e. very slow.

Waste with less activity is disposed of in four rock chambers. The design of the caverns are different and depends on the type and dose-rate of the waste packages. The caverns are about 160 m long and 14 -18 m wide. In one cavern, for intermediate-level waste with a potential for gas generation, remote handling is used as in the silo, while in the other caverns a forklift truck is used for handling.

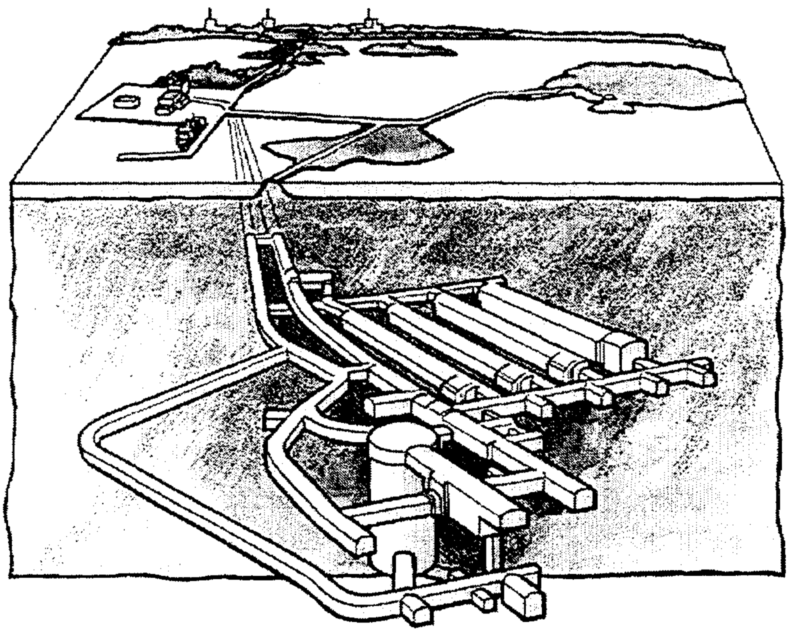

FIG. 3. SFR - The Swedish final repository for radioactive waste

2.2. Long-term safety

The long-term safety of the facility is ensured by the combination of good waste packages, engineered barriers and the isolation provided by the rock [2]. The only conceivable escape mechanisms for the radionuclides from the repository are by moving groundwater or by a well intruding into the repository. SFR has been built underneath the sea bottom because there the groundwater is practically stagnant as no topographical driving forces are present. Also there is no risk for a well being drilled as long as the repository is covered by sea water.

Most of the radioactivity, about 90 %, will be deposited in the silo, which has been equipped with the most extensive barrier system. These are:

- the immobilized waste, and the waste package;
- the chemical sorption on the material in the waste and in the silo;
- the concrete wall of the silo;
- the bentonite clay; and
- the rock mass.

Even in a case of moving groundwater the bentonite will act as a seal and prevent water from flowing through the waste in the silo. In the rock chambers the isolation is provided by the waste itself, the rock mass and in some cases by concrete structures around the waste.

Due to the land uplift in Sweden, about 6 mm/a in the area, the sea bottom above SFR will become dry land in 1500 to 2000 years time, and the hydraulic regime in the rock will change. At this time, however, the most important radionuclides in the waste, Cs-137 and Co-60, will have decayed and only the small amount of long-lived radionuclides like nickel-63 and plutonium will remain. The total amount of plutonium in the repository is expected to be less than 0.5 kg distributed in a large volume.

2.3. Operation of the SFR

Active operation of the SFR started in April 1988. So far about 23,000 m^3 of waste have been disposed of. The facility is operated by a staff about 15 persons, working day shift only. The operation has been subcontracted to the operators of the nearby Forsmark nuclear reactors and is closely integrated in the local organization [3].

Much of the handling in SFR is done by remote control from a central control room. Only during transport of the containers, handling of low-level waste and some closure operations will the operators be exposed to radiation from the waste. The doses to the personnel have thus been very low, on the order of a few mmanSv/year.

3. TRANSPORT

For the transport of spent fuel and waste, SKB has developed a sea transport system. It consists of a special ship, the M/S Sigyn, transport containers and terminal vehicles. Spent fuel is transported from the nuclear power plants to CLAB, and low- and intermediate level waste to SFR [4]. The M/S Sigyn is a roll-on/roll-off ship which makes the waste handling extremely expedient (Fig. 4). She only stays in the harbours at the power plants for a few hours for unloading and loading.

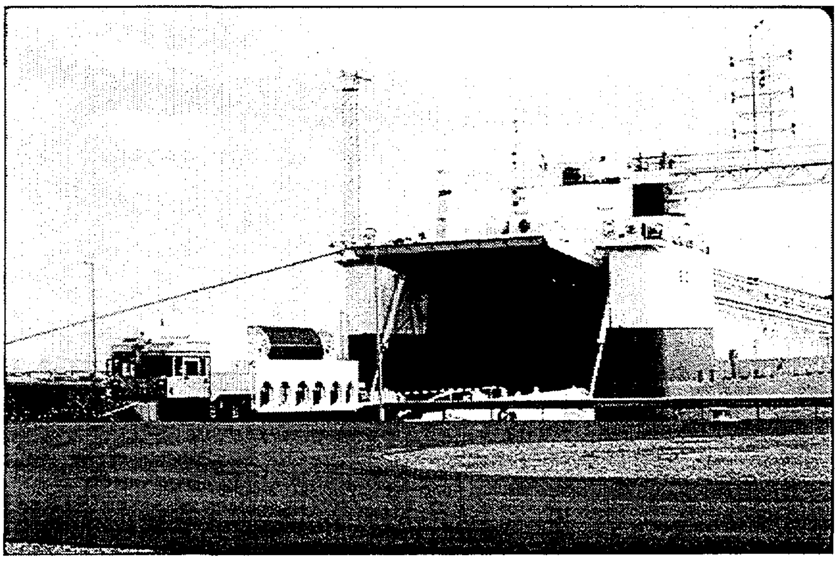

FIG. 4. A transport cask is being loaded on board M/S Sigyn

The low level waste is transported in standard freight containers. For the intermediate level waste that requires shielding a set of large transport containers have been developed. Each container weighs with load about 120 tonnes and can take 20 - 25 m^3 waste. The container has thick shielding walls and can thus take waste packages with a high dose rate. The strongest container used at present can take packages with a dose rate of about 70 mSv/h. By using these shielding containers the waste can be concentrated and the volumes can be lowered. Also a new type B-container that can take packages with even higher dose rates has been developed.

The spent fuel is transported in standardised transport casks of the French TN17/2 design. SKB has a fleet of 10 transport casks that are used for the transports from the nuclear power plants to CLAB. In total some 2,800 tonnes have been shipped to CLAB, corresponding to 970 fuel cask movements.

The performance of the transport system has been excellent with very low doses to the personnel, corresponding to the background radiation. Some factors that contribute to these low doses are the fast and efficient handling and lashing operations for the cask on the transport vehicle and on the ship.

4. CENTRAL INTERIM STORAGE FACILITY (CLAB)

CLAB, the central interim storage facility for spent nuclear fuel is located close to the Oskarshamn nuclear power plant on the Swedish east coast. In CLAB the spent fuel is stored in water filled pools in a similar way as at the nuclear power plants (Fig. 5).

CLAB comprises two parts, one above ground and one under ground. The main building above ground is the receiving building, where the transport casks are received, prepared and unloaded. The unloading is performed in pools under water. The actual storage section is located below ground in a rock cavern, the roof of which is 25-30 metres below the surface [5]. Interconnected with the receiving building are buildings for auxiliary systems, e.g. for water-cooling and purification, and for the electric power and control system.

The storage section, underground, consists of 4 storage pools in a 120 metres long rock cavern. Each storage pool can hold about 1,200 tonnes of fuel in canisters that serve as storage racks. A fifth pool in the cavern is used for transfer of canisters and as a reserve in case of problems with a storage pool. The storage canisters are transported down to the rock cavern in a fuel elevator with a water filled cage.

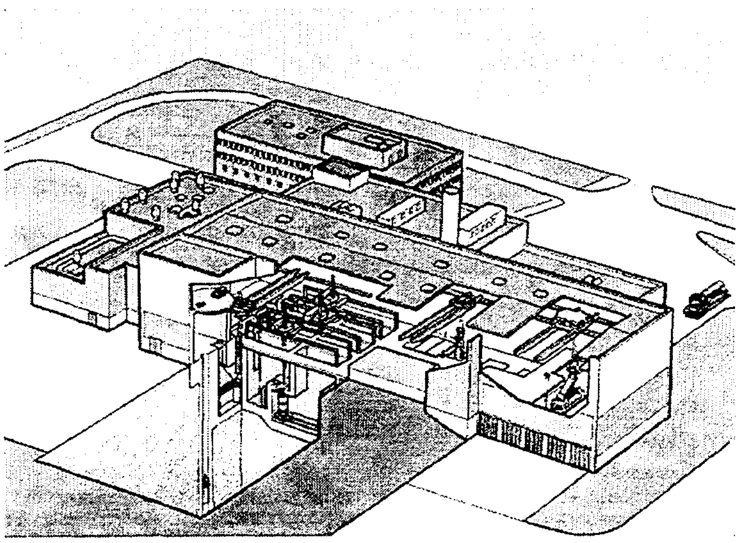

FIG. 5. CLAB, Central interim storage facility for spent nuclear fuel

CLAB was put in operation in 1985, and has thus now almost thirteen years of operation. In total some 2,800 tonnes of fuel have been received, and in addition about 80 transport casks with activated core components, e.g. control rods. The performance of the plant has been excellent and due to improvements, the operating costs have successively been reduced with about 40 % since the start in 1985.

The present capacity of CLAB is about 5,000 tonnes of uranium. This covers the needs until around 2005. From the Swedish nuclear programme, a total of almost 8,000 tonnes are expected to be generated. To accommodate this, CLAB will be extended by building storage pools in a new rock cavern parallel to the existing one. This was foreseen already during the construction of the facility and certain preparations for the extension was made to make it possible to construct a new rock cavern with the existing storage pools filled. The first blasting work for the extension is planned to take place in October 1998. The new pools will be in operation by the year 2004 according to current plans.

In CLAB the spent fuel is planned to be stored for 30-40 years. The fuel will then be encapsulated before being sent to final deep disposal. The encapsulation facility is planned to be built adjacent to CLAB as a direct extension of the facility.

5. DISPOSAL OF SPENT FUEL

In the Swedish system the spent nuclear fuel is planned to be disposed of directly as such. The safety of the repository will be achieved by the application of the following three principles:

- **Level 1 - Isolation.**
  Isolation enables the radionuclides to decay without coming into contact with man and his environment.
- **Level 2 - Retardation and retention.**
  If the isolation is broken, the quantity of radionuclides that can be leached and reach the biosphere is limited by:
  very slow dissolution of the spent fuel;
  sorption and very slow transport of radionuclides in the near field;
  sorption and slow transport of radionuclides in the bedrock.
- **Level 3 - Recipient conditions.**

The transport pathways are controlled to a great extent by the conditions where the deep groundwater first reaches the biosphere (dilution, water use etc.). The safety functions at level 1 and 2 are the most important. They are achieved by means of requirements on the properties and performance of both engineered and natural barriers and on the design of the repository.

To isolate the fuel it will be encapsulated in a canister with good mechanical strength and long-term resistance against corrosion [6]. The conceptual design adopted is a copper canister with a steel insert (Fig. 6). The copper provides a good corrosion resistance in the geochemical environment foreseen in a deep repository in Sweden. The steel insert provides the mechanical strength needed. The function of the canister is to provide adequate enclosure and radiation shielding of the fuel during handling before and during disposal and then provide an absolute barrier against radioactivity release for a considerable time after disposal. The isolation time needed cannot be universally defined. It will depend on the properties of the other barriers, but should at least be 1000 years to provide isolation for the period when the temperature is substantially elevated and when the most toxic fission products Cs-137 and Sr-90 still remain.

Each canister contains about 2 tonnes of spent fuel. The canisters are placed in deposition holes drilled from the floors of tunnels at about 500 m depth in the crystalline, granitic bedrock. Each canister is surrounded by blocks of compressed bentonite. When the bentonite absorbs water from the surrounding bedrock it will exert an intense swelling pressure and completely fill all void space in the near vicinity of the canister with bentonite clay. The clay barrier will contribute to the isolation by preventing or delaying dissolved corrosive species, that may exist in minor amounts in the ground water, to reach the canister. The clay will also provide some mechanical protection for the canister. The tunnels will eventually be backfilled by some material like a mixture of crushed rock and bentonite.

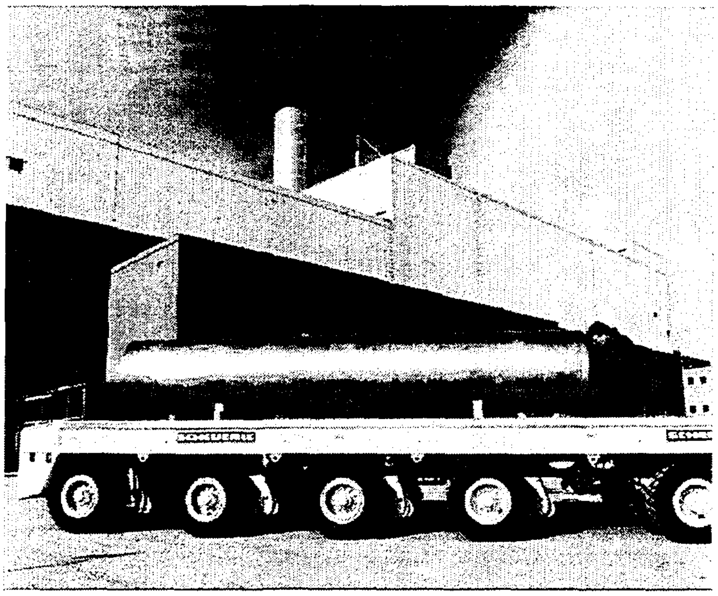

FIG. 6. The copper canister

6. ENCAPSULATION FACILITY

The encapsulation facility is planned to be built as an extension of the CLAB facility. A critical function in the encapsulation facility is the welding of the copper canister. This should be done remotely with a high accuracy, and in a way that can afterwards be controlled by non destructive testing. Different alternatives are being tested. The alternative preferred at present is electron beam welding at reduced atmospheric pressure. The welding technology has recently been demonstrated in full scale. Further development work will be performed to industrialise the process and a welding laboratory at Oskarshamn will be in operation this autumn.

The fabrication of copper canisters of the size needed is by no means an industrially available technology. Full scale canisters have, however, recently been manufactured and further tests are going on.

7. DEEP REPOSITORY

The final step in the spent fuel management chain is the deep disposal of the encapsulated fuel. The disposal will be made at about 500 metres depth. The canisters are deposited in holes drilled from the floors of drifts at a centre to centre distance of about 6 metres. In the holes the canisters are surrounded by highly compacted bentonite (Fig. 7).

The siting of a deep repository is politically sensitive in Sweden as in many other countries. The prime criterion for siting is that the safety requirements can be fulfilled. This puts requirements on the chemical environment, the mechanical stability and the transport conditions in the rock, as well on the risks for future intrusion into the repository. These requirements are expected to be fulfilled at many sites. Other factors such as transports, infrastructure, employment situation and political aspects will also be important for the siting.

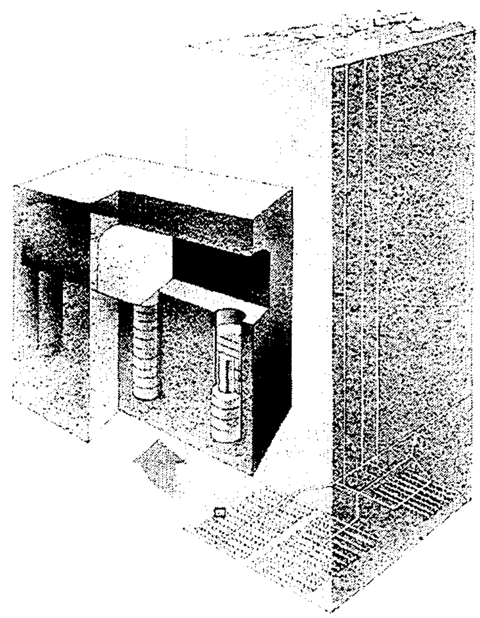

FIG. 7. Deep repository for spent fuel

To facilitate the siting and to clarify that the decision process for siting a repository is a stepwise procedure SKB is planning to start the disposal by first building the deep repository for deposition of a limited amount of spent fuel (about 400 canisters). Then the results will be evaluated before a decision is made whether or not to expand the facility to accommodate all the waste. This plan also makes it possible to consider whether the deposited fuel should be retrieved for alternative treatment. During the first phase it will be possible to demonstrate the siting, licensing, design and construction, handling of the canisters and operation of the facility. The long-term safety of the facility cannot, however, be demonstrated. This must always be based on a technical-scientific assessment.

The deposition could start at the earliest the year 2010. Since a few years SKB has started the work to site the repository. The first step includes general overview studies and feasibility studies in municipalities that show an interest for co-operating with SKB.

A repository is an unfamiliar facility for most people and thus raises a lot of anxiety among many people. One important aspect of the feasibility studies is thus to explain what a repository would mean for a local community. Both positive aspects such as employment opportunities, improvements of infrastructure etc. and negative aspects such as increased traffic, possible influence on tourism, and the risks of the facility itself are covered in these studies. The purpose is to provide a wider base for decision both for SKB and for the Municipality. Feasibility studies are in progress in three communities, all these have other nuclear activities. Feasibility studies in two communities have been abandoned after negative outcome of referendums in 1995 and 1997. All studies are based on a voluntary approach. In total, feasibility studies are planned to be made in at least five municipalities. Two of these will then be chosen for geological site investigations before one is chosen as the repository site. Before the final decision is made to use this site as a repository a detailed site investigation including a tunnel to repository depth will be made.

8. RESEARCH AND DEVELOPMENT

In order to prepare for the siting and construction of a deep repository SKB has built the Äspö Hard Rock Laboratory (HRL). The planning of this facility started some 10 years ago in 1986. The work at the laboratory has proceeded in three stages - planning and site investigations, construction and operation. The first two stages have now been completed and the operational stage has started. A basic objective in the planning of the laboratory was to create a facility for research and development in a realistic and unperturbed environment at a depth planned for the future repository.

The Äspö HRL is designed to meet the requirements on R&D. The underground construction starts with a tunnel from the site of the Oskarshamn nuclear power plant heading north down to about 220 m depth under the island of Äspö. The tunnel then goes down in a spiral with some 150 m radius down to 450 m depth. The total length of the tunnel is about 3,600 m. The last 400 m were excavated by a Tunnel Boring Machine (TBM) as opposed to the first part, that was drilled and blasted. The cross section of the tunnel is about 25 m^2.

Overall objectives for the research conducted at Äspö are to:

- increase the scientific understanding of the safety features and function of a repository;
- develop and test technology that will simplify the disposal concept and decrease costs at retained quality and safety;
- demonstrate the technology that will be used for disposal of spent fuel and other long-lived wastes.

9. INTERACTION WITH THE PUBLIC

The radioactive waste management is not only a technical issue, but has over the years also been a very controversial political issue. In order to proceed with the remaining facilities and notably the deep disposal facility for spent fuel and other long-lived waste it is necessary to gain society's confidence in the methods developed. The difference in opinions of the scientists and of the general public about the safety of radioactive waste disposal has been shown to be very great. It is therefore important to spread knowledge within the Swedish society about radioactive waste and its dangers, about the research being done and about the solutions which have been found.

Open and factual information is a prerequisite for the democratic decision-making process. SKB is contributing to this by a broad distribution of publications and other material, study visit to SKB facilities and various types of exhibitions. Most successful has the mobile exhibitions been that has been arranged on board the M/S Sigyn and with a separate trailer. In total, half a million persons have so far visited the exhibitions. The purpose of the exhibitions is to inform about the waste management, but also, not least, to listen to the worries of the people. The information trailer is also used in SKBs school programme.

In the actual siting work also extensive contacts are taken with the affected population. Information meetings are held, study groups are organized and visits to the existing waste management facilities. During the preparation of the Environmental Impact Assessment an extensive consultation of the public is planned in accordance with the intentions of the Swedish legislation. This work is in progress for the encapsulation plant.

10. CONCLUDING REMARKS

During the last decade a complete system for the management of all radioactive residues from nuclear power production has been developed in Sweden. With the existing systems and facilities the spent fuel and other radioactive waste can be handled safely for a very long time period. The experiences from the operation of the transport system, the interim storage facility for spent fuel and the final repository for short-lived low- and intermediate level waste have been very good.

In parallel an extensive R&D effort has been undertaken to develop a concept for the safe disposal of spent fuel and other long-lived waste in the Swedish bedrock. This work is now going over into an implementation and demonstration phase, with the design of an encapsulation facility and the first phase of a deep disposal facility. In all, this work the political and public acceptance aspects will have an important role. The stepwise implementation is a key element. It must be stressed that no step should really be irrevocable - it should always be possible to step back and reconsider and even take another route.

It is the responsibility of our generation - which has benefited from nuclear energy - to provide the facilities to take permanent care of the radioactive residues. It will be up to the following generations to decide on how to use, extend or change the system we have provided. In this way we can take our responsibility without depriving future generations of their possibilities to take their own actions.

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