THE SWEDISH FINAL REPOSITORY FOR LOW AND MEDIUM LEVEL REACTOR WASTE

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ABSTRACT

A central repository for low and medium level radioactive waste is under construction in Sweden. The repository will be situated in crystalline rock under the sea. The rock caverns are individually designed for different categories of waste.

The most active waste will be disposed of in silos and surrounded by special engineered barriers. Conventional rock caverns with no extra barriers will be used for disposal of mainly low active waste. After the operation period the repository will be closed and sealed.

Then the storage areas will slowly be saturated with groundwater and there will be a potential for activity leakage. The environmental impact of possible releases have been assessed for different scenarios. It is shown that the barrier system, ie the waste itself, engineered barriers and host rock guarantees an acceptably low impact. In the assessment a lot of efforts have been put into studies of processes that could potentially offset the function of the barriers, eg, gas production and waste product swelling.

INTRODUCTION

In July 1983 construction work started on a central Swedish Final Repository for Reactor Waste, SFR. It is located close to the nuclear power plant Forsmark. The facility is designed to accomodate the total amount of low- and medium level radioactive waste from the operation of all the Swedish reactors and the central interim storage for spent fuel (CLAB) up to the year 2010. Similar radioactive waste from research, medicine and industry will also be disposed of in SFR. SFR is scheduled to be taken into operation in 1988. In the future the repository can be extended for disposal of waste from decommissioning and core components.

The Swedish Nuclear Fuel Supply Co, SKBF, which is jointly owned by the Swedish Nuclear Power utilities is responsible for the management of wastes from nuclear power in Sweden (Fig. 1).

REACTOR WASTE

The waste from reactor operations consists of wet wastes, such as ion-exchange resins, sludges and filters, and dry wastes, such as discarded equipment, overalls and paper cloths.[1]

The wet wastes contain most of the activity and are normally solidified at the reactor stations. Cementation is used at two sites and bitumenization at the other two. The cemented waste is contained in cubical concrete containers with 1.2 m side, and the bitumenized waste in standard 200 l drums. Some low-active resins from the condensate clean-up system is dewatered and stored without solidification in large transportable concrete tanks.

Dry combustible waste is sent to the Studsvik research facility where it is incinerated.[2] The ashes are incorporated into cement. Non-combustible solid waste is compacted and packaged.

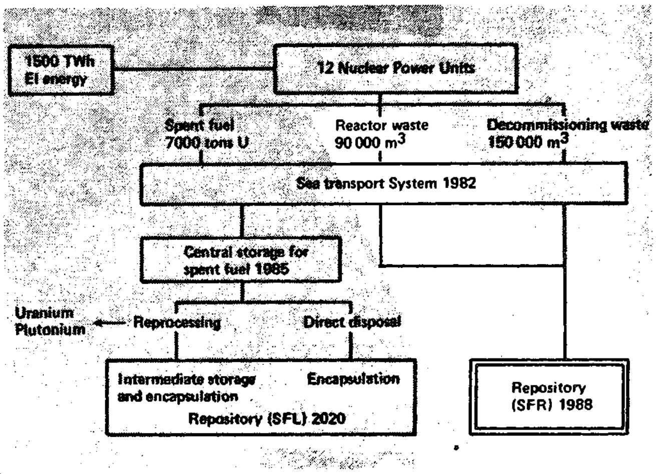


Fig. 1. System for management of radioactive waste in Sweden.

SFR will thus receive a variety of packages and waste products ranging from quite "hot" 200 l drums to standard freight containers with practically no activity. The total quantity of reactor waste in Sweden up to the year 2010 is calculated to be about 100 000 m^3. Of this more than 90% comes from the operation of the reactors and CLAB. The future decommissioning of the reactors will contribute with a similar volume of waste.

LOCATION AND DESIGN OF SFR

The repository is co-located with Forsmark nuclear power plant at the Baltic Sea on the east coast of Sweden. Rock caverns will be built in crystalline

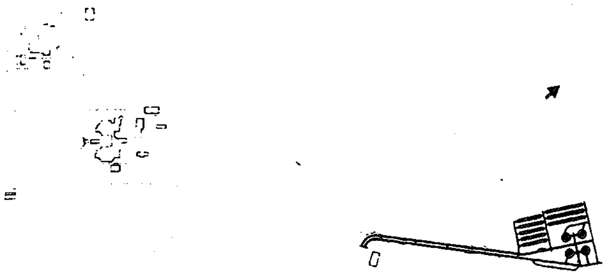


Fig. 2. Location of the repository at Forsmark nuclear power plant.

rock under the sea 1 000 m from the harbour in Forsmark, (Fig. 2). The rock cover will be at least 50 m from the top of the caverns to the sea bed. The water depth in the area is 5 m.

In Sweden there is a lot of experience from excavation of a large number of rock caverns with dimensions comparable with, or larger than, those planned for this repository. The experience shows that very good stability can be obtained with conventional methods for reinforcement of the rock.

Two tunnels are at present being excavated from the harbour to the area chosen for the rock caverns. One of the tunnels will be used for transports during the operation period. It also accomodates installations of pipes and ducts. The other tunnel is mainly being used during the construction period, but it is also a reserve tunnel during the operation period.

The layout of the storage facilities is dependent on the nature of the waste, its quantity, composition and handleability. Different types of storage rooms for different kinds of waste have therefore been found appropriate.

Most of the waste, primarily solidified ion-exchange resins, will be stored in the silo repository. This will contain approximately 95% of the activity disposed in SFR. The silo repository is therefore designed with special engineered barriers.

Other parts of the repository containing low-active wastes have no other barriers than the surrounding rock and the waste package itself.

In addition to the storage rooms, the facility will include areas for transport and handling of the waste, control rooms for the remotely controlled disposal operations and service and personnel areas.

The silo repository

The storage area where most of the activity will be disposed of is called the silo repository. This part is designed as rock caverns, 60 m high and 30 m in diameter. In the rock caverns 50 m high concrete silos will be built using the slip-form method. The concrete

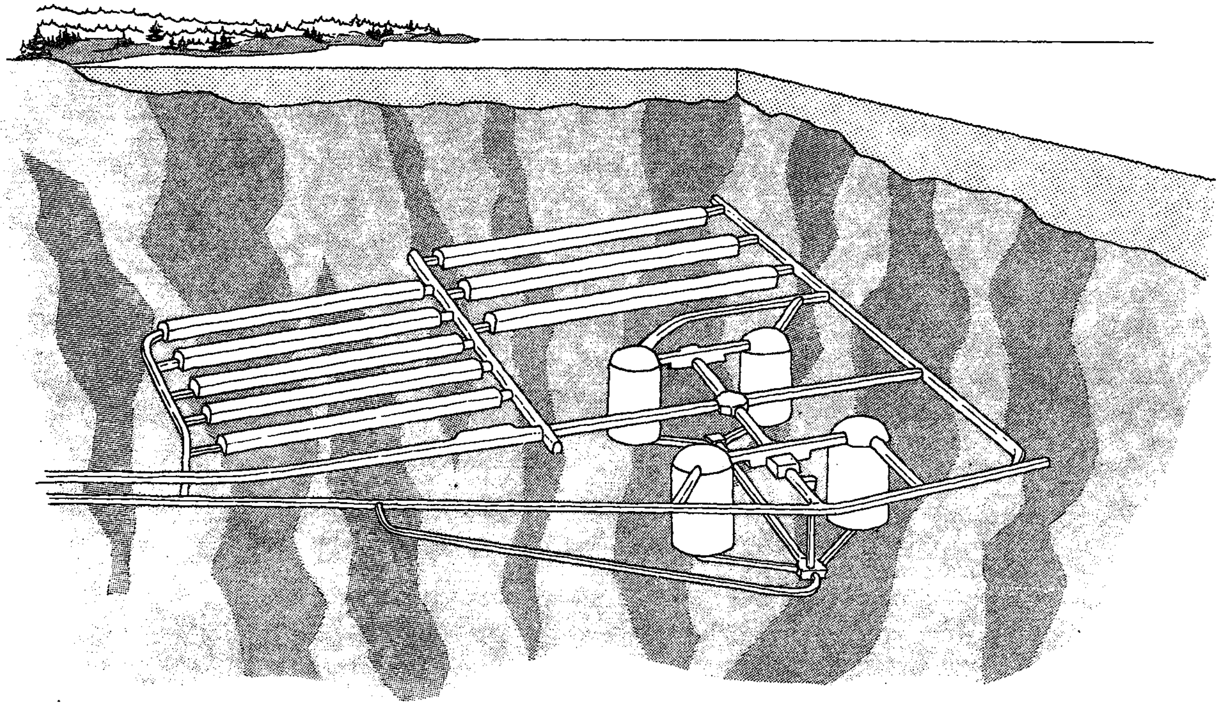
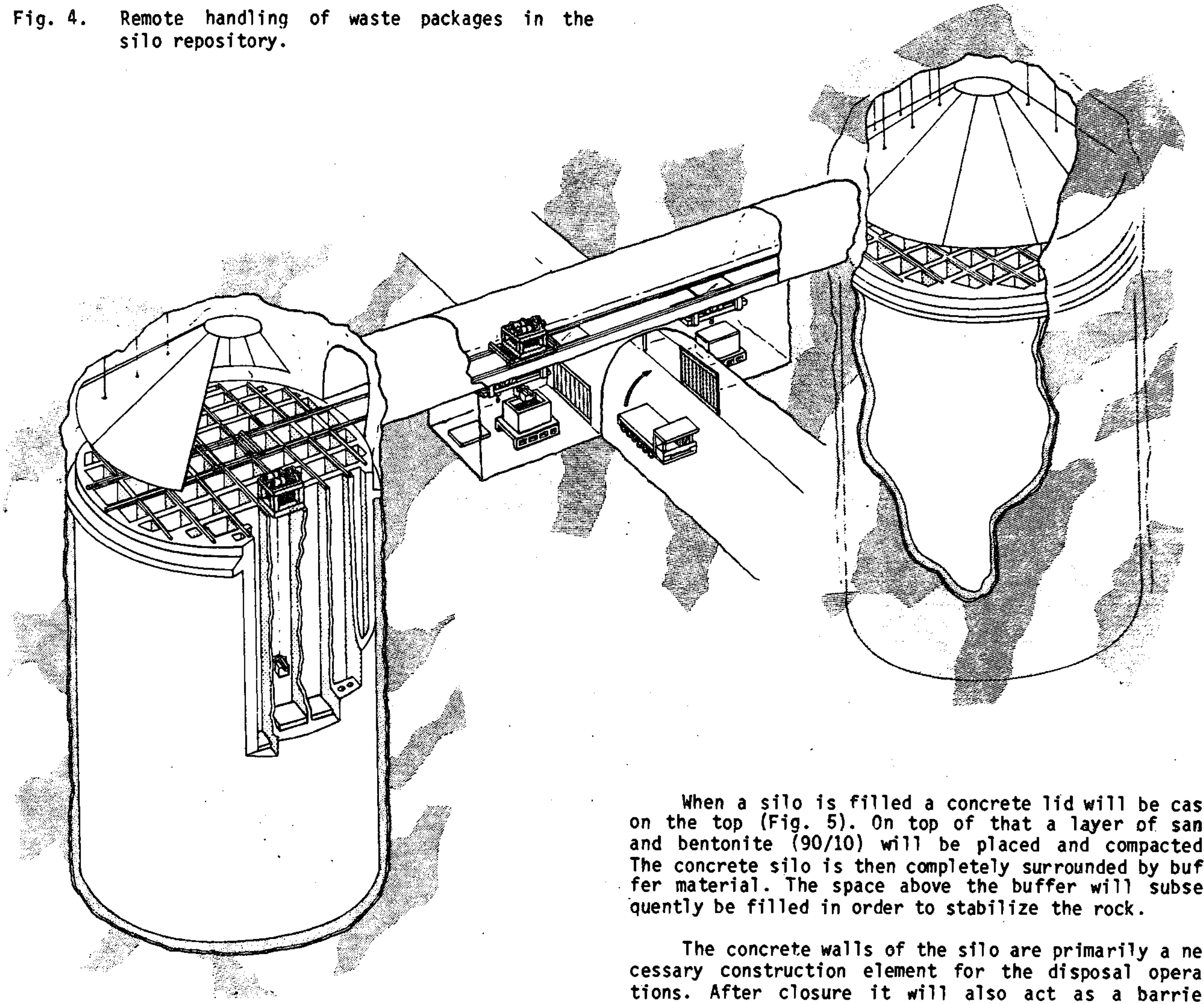


Fig. 3. General lay-out of the repository.

Fig. 4. Remote handling of waste packages in the silo repository.



silos are 25 m in diameter and equipped with internal walls. These walls divide the silo into 2,5 m wide squared shafts.

The concrete silo will be built on a bed of sand and bentonite (90/10). The space between the walls and the rock will be filled up with pure bentonite or a mixture of sand and bentonite (70/30). Pure bentonite can be filled into a narrow slot without compaction while a 30/70 mixture has to be thoroughly compacted and therefore need more space between the concrete silo and the rock. Tests are at present carried out on both alternatives and after the evaluation of these tests it will be decided which method that will be used for the wall-buffer.

The handling of waste packages in the silos are fully remotely controlled. A special vehicle brings the waste in a shielded container to an unloading position (Fig. 4). The lid of the container is removed by an overhead crane, and the waste packages are unloaded with a handling machine that transport them to one of the concrete silo where they are lowered in the square shafts. The waste is subsequently surrounded by concrete grout.

When a silo is filled a concrete lid will be cast on the top (Fig. 5). On top of that a layer of sand and bentonite (90/10) will be placed and compacted. The concrete silo is then completely surrounded by buffer material. The space above the buffer will subsequently be filled in order to stabilize the rock.

The concrete walls of the silo are primarily a necessary construction element for the disposal operations. After closure it will also act as a barrier against release of radioactivity. The main barrier, however, is the clay buffer which guarantees that there will be practically no water flowing through the waste.

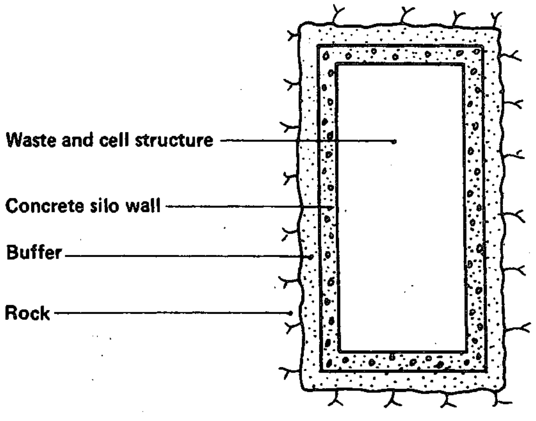


Fig. 5. Barriers in the silo repository.

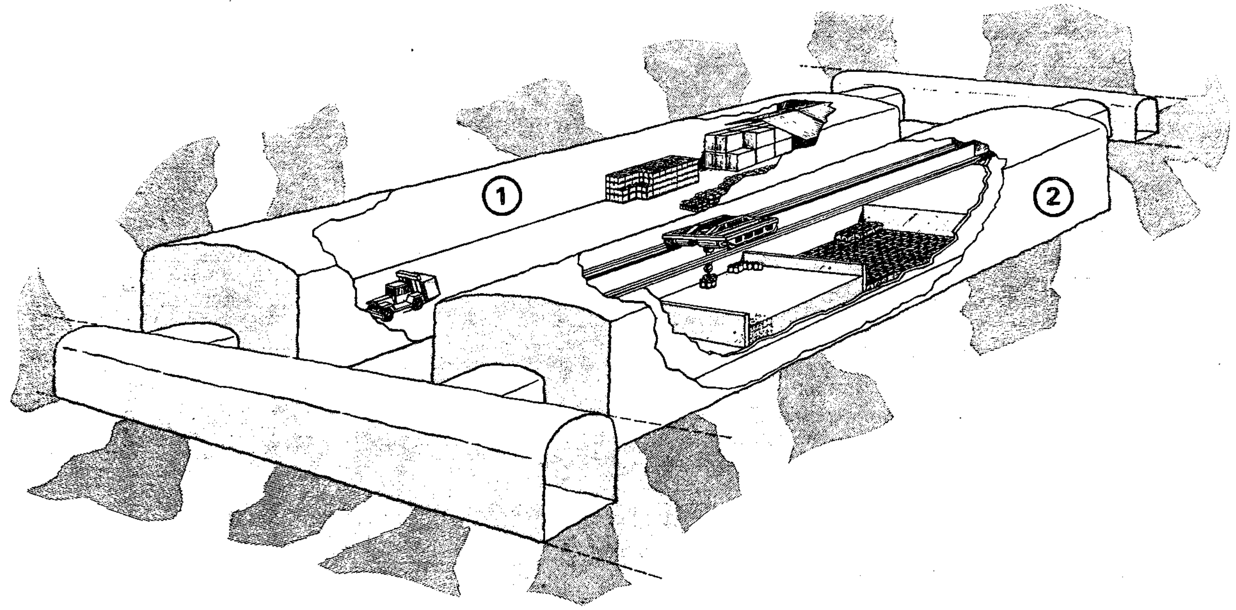


Fig. 6. The rock caverns for low (1) and medium (2) level wastes.

Rock caverns

For the less active waste rock caverns will be used. The design of the rock caverns is dependent on the type and dose rate of the waste packages.

One of the caverns is designed to accomodate waste which requires shielding during transport and disposal. These packages are transported and handled in the same way as in the silos (Fig. 6). The cavern is divided into big boxes with concrete walls and an overhead crane places the packages in one of these boxes. Some of the waste will subsequently be surrounded by concrete grout for stabilization.

The concrete tanks that are used for storage of dewatered powder resins will be deposited in a specially designed rock cavern. The size of the tanks is 1.2 x 3.2 x 2.2 m and they are stored in two layers (2 x 2.2 m). The tanks are stabilized by concrete grout when a number of 80-100 tanks are deposited, which means approximately once a year.

The rock caverns designed for low level waste will mainly accomodate standard freigth containers, steel drums and steel boxes (Fig. 6).

When the repository is filled up the caverns will be sealed with concrete plugs in the entrance tunnels. It might also be necessary to fill part of the empty space in some caverns to prevent the rock from caving in. This will only be the case if the rock mass locally is of poor quality.

When the whole repository have been filled up and closed the tunnels will also be sealed at ground level in order to prevent future intrusion. The buildings at ground level will be demolished and the area will be restored.

TRANSPORTATION OF WASTE

The Swedish nuclear facilities are all located on the coast. A sea transport system has therefore been found to be appropriate and a special ship has been built. This ship, together with special land transport vehicles, have been in operation since 1982 for transports of irradiated fuel. The same ship and the same type of vehicles will be used for transportation of waste to SFR. Low level waste can also be transported on road in standard freight containers.

Special large sized containers will be designed for the transport of such reactor wastes that needs shielding. They will have a weight with load of about 120 tonnes and a capacity of 15 - 30 m^3 of waste each. For the construction of the containers steel and concrete are being studied. A prototype in steel will be manufactured and tested this year. The feed back from this manufacturing and testing period will be a base for the design of the different containers.

ENVIRONMENTAL IMPACT

During the operational phase the radiological impact on the environment is practically nil. No release of any magnitude can be foreseen, either via air or via water, since only contained wastes will be handled.

After the repository has been filled up with waste, the facility is closed and sealed. The purpose

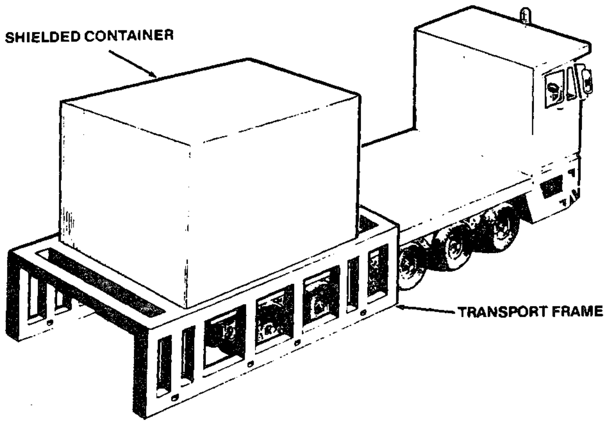


Fig. 7. Transport container for intermediate level waste. Special transport vehicle.

of closure is, first to complete the engineered barriers and, second to prevent access to the facility. Even if it is foreseen that knowledge of the existence of the facility shall be maintained for at least a few hundred years, the design of the repository is such that its safety is not dependent upon such a knowledge.

After closure of the facility the engineered barriers and the host rock guarantee that the leakage of radionuclides from the repository will be kept at an acceptably low level.

SFR consists, as was described earlier, of different storage areas, with different engineered barriers, depending on the waste to be disposed of. In the long term perspective the primary function of the engineered barriers is to limit the release of radioactivity from the repository. In some cases, this function is obtained without any extra cost, since the barrier is a necessary part of the design, eg to enable a safe handling of the waste. An example of this is the concrete silo in the silo repository. Other barriers, the backfill material, are entirely applied to ensure the long-term safety of the repository, by limiting the water flow through the repository and by supporting the rock from caving in.

Different backfill materials will be used to give the desired function. Where the supporting capacity is important, materials with low compressibility will be used, eg, sand and blast rubble swelling. Clay will be used to limit water flow.

Radioactivity in SFR

In the reactor waste Co-60 and Cs-137 are the radionuclides of greatest interest. The latter will determine the toxicity of the waste in SFR for 500 - 1 000 years. After that, the very low content of transuranium elements in the waste will dominate. The total amount of Cs-137 in the reactor waste from the 12 Swedish reactors is estimated to be 3 x 10^6 GBq by 2010.

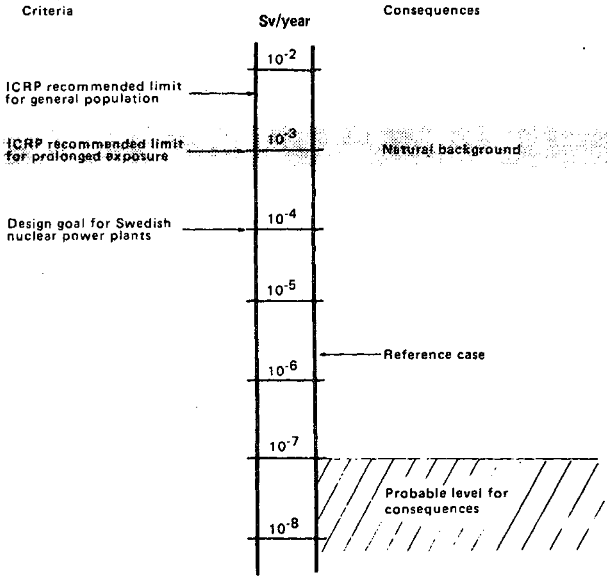


Fig. 8. Calculated radiological impact of SFR 1.

Safety assessment

The only conceivable means for the release of activity from SFR is by transport with the groundwater. During the years immediately following closure of the facility, the rock volume drained during the operational phase will be recharged with water. This will restore the natural hydrogeological conditions in the rock quite quickly. The time needed to saturate completely the silo repository will, however, be much longer since the silos are surrounded with materials of low permeability. Only then can the transport of radionuclides out of the repository start.

Figure 5 shows the barriers in the silos. Due to the low hydraulic conductivity of the buffer material, the main transport mechanism for the radionuclides will be diffusion, which guarantees a very low release rate. In the rock caverns, where only a small fraction of the activity is placed, the waste itself and the rock give the necessary barrier function. Here the release rate is determined by the rate of groundwater exchange.

The location of SFR under the bottom of the sea ensures that the hydraulic gradient and thereby the groundwater movement is very slow and thus the rate of exchange is low. It also provides a recipient, the sea water, with a high dilution capacity. This is true for at least 1 000 years while the most important radionuclides decay. Thereafter, the land uplift (at present 6 mm/year) may have moved the bottom up above the sea level and the primary recipient will be a freshwater lake. The location of SFR under the sea also ensures that no well will be drilled in the vicinity of the repository, which could bypass the barriers. The result of the safety assessment is illustrated in Fig. 8. A conservatively calculated dose to the most exposed individual is 3 µSv/year. The real dose will most likely be considerably lower.

Lessons learned

The most important lesson learned from the safety assessment for SFR is that the leaching characteristics of the waste are not decisive for the safety. As long as the barriers have their intended function the release rates from the repository would be low enough even in the case that the activity is not bound to a matrix.

Of greater importance in the safety evaluation are processes that could potentially offset the function of the barriers. Examples of such processes are gas production and waste product swelling. A lot of efforts have been put into studies of processes that could give these effects, and still more is planned before the facility is taken into operation. Gas production can be due to radiolysis, microbial attack and corrosion, the combination of the latter two being the most important. Swelling may occur in bitumenized ion-exchange resins.

LICENSING SITUATION

In March 1982 SKBF applied for a license to build and operate SFR. The application was based on a preliminary safety report, which then was scrutinized by the Swedish authorities during somewhat more than a year. In late June 1983 the Government granted a license to start construction.

The license to build SFR is connected with certain stipulations. The most important are:

- SKBF shall continously give information to the public about the progress of the project and the safety against radioactive release from the repository.
- The total amount of disposed activity is limited to 10^{16} Bq.
- A comprehensive control program backed up by a test- and verification program shall be carried out.
- Further studies of gas production reactions are requested as well as a study of gas transport capacity of the rock.
- The silo repository was not considered satisfactory for bitumenized waste and a new design was therefore requested.
- The Swedish Nuclear Power Inspectorate shall scrutinize the design and construction work and if necessary announce additional requirements.
- Before commissioning of the repository SKBF has to apply for a license to operate the facility. The application will be based on a final safety report.

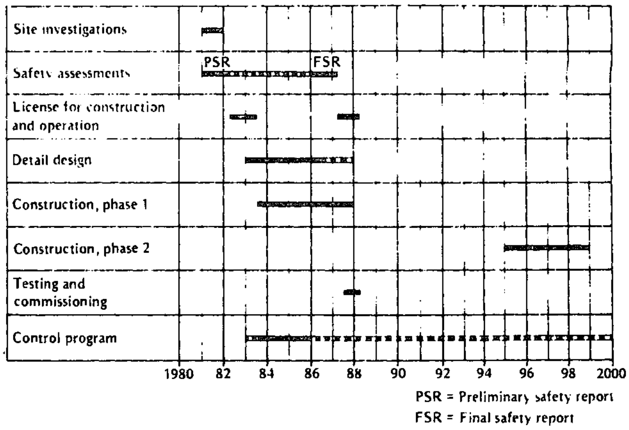


Fig. 9. Time schedule.

- The final sealing will require a special license based on a new evaluation of the safety assessment.

TIME SCHEDULE AND COSTS

The two tunnels have in early February 1984 reached 250 m into the rock. The repository level will be reached at the end of this year, when the excavation of the caverns is planned to start. Gradually the concrete works will start in late 1985 when the first caverns are excavated. The first silo will be built in 1986-1987.

In mid 1986 the installation work begins and shall be finished by the end of 1987. The commissioning is planned to April 1988 when the first waste is sheduled to arrive.

The first phase will be finished at the end of 1988 by the commissioning of the second silo. This phase is at present planned to comprise two silos and five caverns. A second phase with two silos and three caverns is planned to be built at the end of the 1990s.

SKBF has contracted the Swedish State Power Board for the detailed design and construction of the repository. The total cost for this work is calculated to be about 900 MSEK (million Swedish kronor) for phase one and two. Costs for operation and sealing of the facility have been estimated to be about 300 MSEK. The costs are given in 1982 prices and do not include interest during the construction period.

Conventional techniques will be used for the construction work. They will, however, be complemented by an extensive investigation program including

- Continuous investigations of the rock mass during construction by core drilling and measurements of the hydraulic conductivity

* Evaluation of the result from the investigations and preliminary design of reinforcement of the rock mass

* Calculation of changes in deformations and rock stresses during different phases of the excavation work

* Use of special methods for cautious blasting which ensures very limited damage in the remaining rock

* A thorough follow-up of the geological situation by examination of the rock surface after the blasting

* From the result of the geological follow- up, a program for final reinforcement of the rock mass can be determined and carried out

* Measurement of deformations in different sections which can be compared with calculated data for these deformations.

Up to now, investigations in cored boreholes of the rock mass have been made. In order to show the feasibility of the dimensions of the caverns and especially the silos from a rock mechanics point of view, calculations have been carried out and presented as a document in the licensing process. The other steps mentioned above will be taken during the excavation and be included in the control program.

In parallel with the excavation and construction work a test- and verification program will be performed. The purpose of this is to verify that the safety-related functions of the barrier components in the real repository environment are at least as good as have been assumed in the safety assessment. This program includes experiments on the waste and the engineered barriers. Primarily, effects that could potentially offset the barrier function will be studied as exemplified earlier.

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