THE SWEDISH FINAL REPOSITORY - SFR FOR LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE

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ABSTRACT

SFR, the Swedish Final Repository for Radioactive Waste, has been designed for LLW/ILW from the operation of the twelve Swedish Nuclear Power Plants. To the year 2010 a total production of electricity from the NPPs in Sweden will be around 2000 TWh, or approximately 350 reactor years. This energy production will give raise to approximately 90000 m^3 of Low- and Intermediate level waste, including packagings, for disposal in SFR.

SFR has been in operation since 1988. More than 11000 m^3 of waste has been disposed of today. The operation is assumed to continue until, at least, the year 2010. An extension for decommissioning waste is foreseen at 2010 - 2020.

The repository, located in the bedrock 60 m below the bottom of the Baltic Sea, consists of different disposal chambers with different barrier systems. The most active waste is deposited in a concrete silo surrounded by a clay buffer. The silo will contain 90 % of the activity. The remaining 10 % is disposed of in rock caverns with different concrete structures depending on the geometry of the packages, activity contents and the handling strategy.

The post-closure safety of the repository has been analyzed in detail as part of the licensing procedure.

The long term safety is dependent on the function of the engineered barriers and on the ground water movements in the area - from the repository to a recipient.

The safety assessment is based on a systematically performed scenario analysis. In the scenario analysis all possible situations (Features, Events and Processes) are looked upon. They are described in the form of "Event trees" and, after screening out insignificant branches in the Tree, Scenarios are formulated for further analyses. A base case is formulated for each part of the repository and for each time period of concern (recipient changes with time). In the base case conservative but realistic parameter values are chosen. Sensitivity analysis are performed for selected parameters.

INTRODUCTION

The twelve Nuclear Power Plants in Sweden will produce approximately 2000 TWh electricity up till the year 2010. This energy production will also give raise to approximately 7800 t spent fuel, 90000 m^3 of conditioned operational waste and 100000 m^3 decommissioning waste.

In this paper the design, operation and post-closure safety assessment of SFR is discussed. SFR will have, after a foreseen extension, a capacity to receive all LLW/ILW from the operation of the Swedish Nuclear Power Plants until the year 2010. The first phase, now in operation, has a disposal volume of 60000 m^3.

The repository is designed to contain the radionuclides for such a long time, that the radionuclides decay to an insignificant level in the repository or that the release will be so slow that the concentration in the biosphere will be insignificant.

LICENSING PROCEDURE

Generic studies were performed during the mid 70ies. The result was that an underground location should be chosen and that, if possible, no institutional control or corrective actions should be necessary after closure of the repository.

A Preliminary Safety Analysis Report (PSAR) was given to the Government in 1982 after siting and design studies.

Construction permit was given in 1983 by the Government. The excavation started in the autumn that year. During the construction work continuing research and detailed design studies was done. A Final Safety Analysis Report was prepared in 1987.

The license for operation was given in March 1988 by the Swedish competent authorities SKI (Swedish Nuclear Power Inspectorate) and SSI (Swedish Radiation protection Board) and in April the first waste was deposited.

The operational license includes some requirements on further research, complementary analysis etc.

A complementary safety evaluation will be required before a permission for sealing is given.

All wastes to be deposited need special approval from the authorities.

GENERAL DESIGN OF THE REPOSITORY

The repository is located close to the Nuclear Power Plant at Forsmark, in the crystalline bedrock (gneiss and granite), 60 m under the Baltic sea. This location ensures a very small hydraulic gradient and thereby the ground water is almost stagnant. The location also ensures that no one will drill for drinking water in the area at least for a period of about 1000 years. After that the land uplift will raise the shallowest sea bed formations above the sea level.

An implication of the location is that no institutional control period is needed or planned after closure of the repository.

SFR has different disposal chambers for different kinds of waste. The most active waste is disposed of in a concrete silo surrounded by a bentonite clay barrier. About 90 % of the activity in the repository will be directed to the silo. The remaining 10 % of the radioactivity will be allocated to more simple rock caverns.

The layout of the tunnels and caverns is shown in Fig. 1.

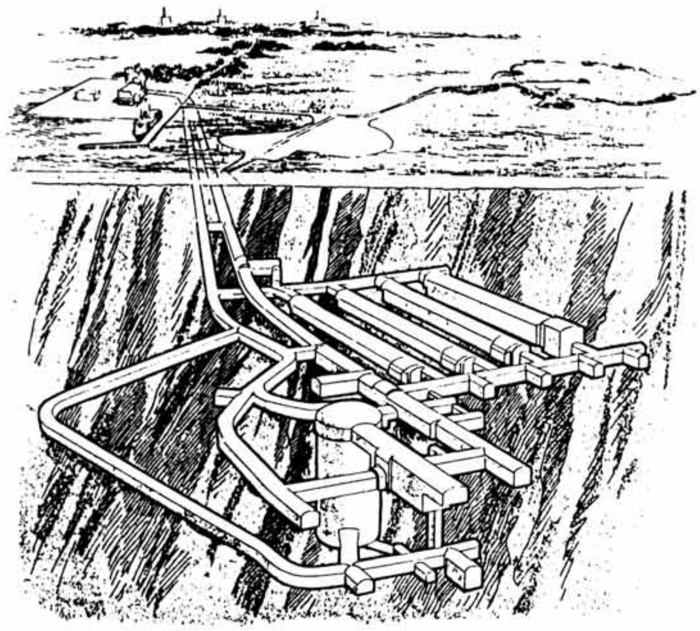

Fig. 1. General layout of SFR, phase 1.

OPERATION

After being treated and packed by the waste producers, the waste packages are loaded into shielded transport containers and transported on board the ship m/s Sigyn to SFR.

A special transport vehicle carries the containers on and off the ship. The vehicle is also used to carry the containers down into the repository.

After the documentation has been checked the transport container can be emptied. The unloading takes place in separate unloading positions in each disposal chamber. Low level waste is handled by a shielded fork lift truck. Intermediate level waste is handled remotely by traverse cranes installed in one of the caverns and in the silo.

BARRIER PERFORMANCE AND PROCESSES

Many studies concerns the understanding of chemical and physical processes which may influence the long-term performance of the SFR repository. The repository is, after sealing, considered to be completely saturated by oxygen free water, saline at first but than changed to fresh water. The ground water is almost stagnant during the first 1000 years after sealing, but the flow will then increase as land rises. Some of the more important issues are briefly described in the following.

Waste and Additives

In order to be able to perform the safety analyses, some assumptions concerning the waste and the influence of the waste on the barriers has to be made. Examples are activity content, mechanical strength, contents of complexing agents or potentially complexing substances, gas production and swelling.

To make sure that the waste are within specified limits all types of waste has to be accepted for disposal before transport to SFR. Acceptance is given by the authorities based on a special Safety Report for each category of waste (Waste Type Description, WTD). SKB has to present these WTD's to the authorities before getting a permit for disposal. A WTD is established in cooperation between SKB and the waste producer.

The WTD includes:

- functional requirements for each step in the handling sequence, from collection of raw waste through treatment/conditioning, storage on site to transport and disposal in SFR
- a "translation" of functional requirements into requirements on mechanical, chemical and radiological properties. Limiting values on each property is given. The set of limiting parameter values is regarded as Waste Acceptance Criteria for this particular waste type.
- description of performance tests and analyses to verify the required properties and definition of necessary control actions to assure the quality of the waste package.

After approval the WTD is a part of the Final Safety Report.

Some properties, essential for the safety assessment, are not related to individual waste packages but to the repository or disposal cavities as a whole. Examples on such properties are:

- radionuclide content,
- content of complexing agents,
- content of organic material,
- content of material with potentially high gas formation rate

The contents of these materials are declared in the WTD's and if possible measured and recorded. Record keeping at the repository and administrative procedures will assure that the limitations on disposal cavities or the repository are not surpassed.

Concrete Barriers

The most important properties of the concrete concerning the long term performance are low hydraulic conductivity, low diffusivity, high sorption capacity and high mechanical strength. This can easily be achieved in fresh concrete but some of the radionuclides have such a long half life that it is important to see how these properties are changed with time.

Chemical processes influencing the concrete are for example leaching, ettringite formation and chloride intrusion.

Physical processes are cracking, swelling of ion-exchange resins, uneven swelling of the bentonite barrier around the silo, rock movements etc.

As backfill in the silo a special permeable grout has been developed. The desired performance, like high permeability and extremely good workability, is due to the assumed gas formation inside the silo which has to be able to escape without building up high pressure that the silo can not withstand.

Bentonite Barrier

Bentonite is a natural clay material which is very stable in the Swedish crystalline rock. The clay is Sodium treated which means that it can affect concrete by forming ettringite. For this reason a Sulphate resistant cement is used in SFR. The silo is shown in Fig. 2.

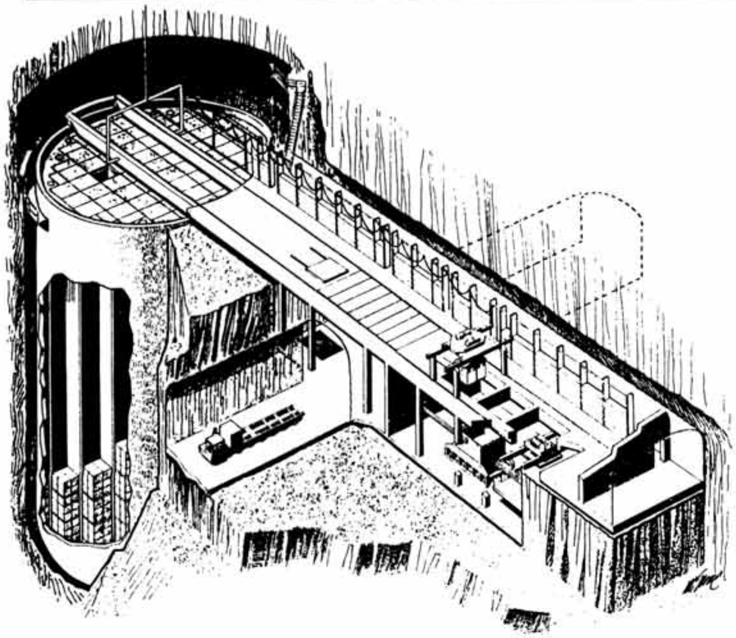

Fig. 2. Design of the silo.

Gas Formation

Gas may be produced due to anaerobic corrosion of steel and other metals, radiolysis or microbial degradation of organic materials. Gas has been found to be of interest in connection with the silo only. In the rock caverns there is large capacity for gas transport while in the silo special efforts has to be taken to let the gas out. In the silo only gas produced by corrosion of steel could be significant. Experimental results estimates the steel corrosion rate to 1 - 10 μm/a which corresponds to 500 - 5000 m^3(STP)H_2/a in the Silo.

Hydrogeology

A lot of field data concerning the hydrology in the repository area has been recorded before, during and after excavation. A conceptual model was established and used for numerical modelling of the ground water flow in the area. A detailed evaluation of the transient movement of the boundary between salt and fresh water due to land uplift has been performed. Risk areas for future wells in the area as well as a conservative estimation of the dilution of water flowing from the repository to the well is included in the evaluation.

It has been concluded that even though the coast line is on top of the repository after 1000 years it is likely that a fresh water based environment will not be established until 1000 to 2000 years later.

SAFETY ANALYSIS

The purpose of a Scenario Analysis is to perform a systematic review of all possible changes that can occur inside and around the repository and to make clear their importance to the release of radionuclides from the repository and finally to give the probabilities of the changes to occur. In this paper a short summary of the methodology used for SFR is given.

Scenario Identification and Formulation

Methodology: The first step, in the methodology for identification and formulation of scenarios for the release of radionuclides from SFR, was to identify all Features, Events and Processes (FEP's) that may influence the long term performance of the repository. All FEP's were documented in short memo-texts.

After identifying the FEP's a first description of the system was made in a graphical form as "Event Trees" (Figure 3), one for each disposal part of the repository. Each tree was constructed by starting with the top event, the release of radionuclides to the biosphere and than moving inward barrier by barrier towards the initial source, the waste matrix, linking FEP's together in branches according to cause and effects.

The first graphical description was constructed with the purpose to include all phenomena that may influence the release to the biosphere during all times.

Based on this graphical description a verbal description of the performance of the repository in terms of transport pathways, initial state and evolutionary processes in the different barriers was performed. This work also involved screening out phenomena which at this stage could be assessed to have negligible consequences compared to other phenomena. The Event Tree was here used as a tool to ascertain that the simplifications made were logical and consistent.

Finally, scenarios for the release of radionuclides to the biosphere were formulated for the different repository parts, a reference scenario which, with present degree of knowledge and understanding, describes the most realistic course of

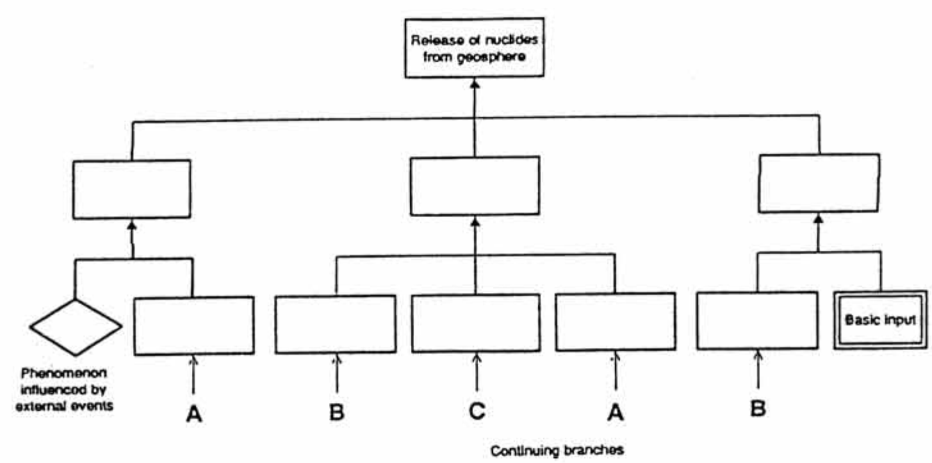

Fig. 3. Schematic illustration of Event Tree.

events as well as some more extreme and conservative scenarios which potentially could result in higher doses to man.

Nuclide Release from the Silo

The release of radionuclides from the silo will be dominated by diffusion for a long time. After degradation of the engineered barriers in the silo groundwater starts to flow through the silo. The release is strongly retarded by sorption in concrete and bentonite.

The assumed gas formation will displace some water by flow from the internal of the silo to the sand/bentonite buffer on top.

Nuclide Release from the Caverns

The release of radionuclides from the different cavers is governed by advection and diffusion to the moving groundwater where advective transport dominates.

No solubility limitations are assumed for the radionuclides.

Nuclide Transport in the Geosphere

Phenomena, identified to primarily influence the release to the biosphere are:

- the groundwater flow in the rock,
- matrix diffusion,
- sorption and
- dilution.

Radionuclides released to the geosphere will follow the groundwater flow in fractures and fracture zones in the rock. Depletion from the groundwater will occur by diffusion into stagnant water in microfissures and pores in the rock matrix. Nuclides are also retarded due to sorption onto fracture surfaces. Finally, groundwater containing radionuclides will mix with groundwater which has not passed the repository.

Scenario Analysis

- It must be stressed that, although the safety assessment considers calculations of releases and consequences of releases, the most probable situation is a no-release situation.

Reference Scenario

Three principally different escape mechanisms can be identified for the release of radionuclides to the environment:

- radionuclide transport by flowing groundwater in the rock,
- radionuclide transport in the form of gas, and
- human intrusion

Only the first mechanism needs consideration in the reference scenario. After land rise and establishing a fresh water environment intrusion is considered as an extreme scenario.

During the Salt water Period, when the Baltic Sea covers the repository, the groundwater is almost stagnant. The bentonite clay around the silo has a very low hydraulic conductivity which means that diffusion is the dominating release mechanism from the silo. Due to gas production an initial pulse of potentially contaminated water can be pressed out from the repository. During the Salt Water period only insignificant degradation of the engineered barriers are foreseen. The main pathway for radionuclides to man is the eating of fish from the Sea. Calculated doses for this period is small compared to the design goal, less than 1 μSv, dominated by Cs-137 and Co-60 from the caverns. The Silo contribution is only 2 nSv/a in the Reference scenario.

The ongoing land uplift in the repository area is about 6 mm/a. After 1000 years the shore line will pass the repository and the Inland period starts.

As for the Saltwater Period the maximum annual individual dose commitment during the Inland Period is very low, approximately 4 μSv from drinking water. Dominating nuclides are C-14 from the Silo and Pu-239/240 from the caverns. Assuming strong complexation from degradation of cellulose the calculated dose might increase to 20 μSv/a, which is still well below the design goal.

The collective dose from SFR is dominated by release of organic C-14, which conservatively is assumed to exist in the waste. The dose is negligible compared to the normal release of C-14 from the Nuclear Power Plants.

Extreme Scenario

Extreme scenarios for the Salt Water Period is concentrated to the performance of the silo. Different disturbance scenarios with clogging of gas vents, initial fractures in the wall, decreased conductivity in the porous backfill concrete etc has been analyzed. There are no situations where the release from the silo will dominate significantly over the caverns.

Extreme scenarios for the Inland Period is disturbances in the silo or a "Well scenario" where a well is drilled into the repository.

The silo disturbance scenario has been chosen to be a combination of clogging of gasvents and a fracture in the bottom as soon as the shore line passes the repository, 1000 years after sealing. The maximum release of radionuclides will in this case be 10 to 20 times the release in the Reference Scenario for the silo and is dominated by C-14.

Drilling a well into the repository after 1000 years means that the well has to be just at the shore line which is very unlikely. To illustrate the consequences calculations has been performed showing a maximum dose of 2 mSv/a. As a comparison it can be noted that normal drilled wells in Sweden might give as much as 5 mSv/a due to natural radon in the rock.

SUMMARY AND CONCLUSIONS

SFR has been designed to make possible a simple and controllable as well as a safe disposal of low- and intermediate level radioactive waste from the operation of the Nuclear Power Plants in Sweden.

The siting and layout of the facility is aimed to prevent radionuclides from leaving the repository in unacceptable concentrations. The post-closure safety shall not be dependent on control or corrective actions.

The environmental impact of the repository has been analyzed, based on the "Event Tree" technique. Calculated doses during the first 1000 years after sealing of the repository (the Salt Water Period) are insignificant and with reasonable conservative assumptions concerning release during the Inland Period, more than 1000 years after sealing, the doses are well below the design goal of 0.1 mSv per year to any individual.