THE POTENTIAL FOR RETRIEVABILITY AND APPLICATION OF MONITORING WITHIN THE KBS-3 CONCEPT FOR FINAL DISPOSAL OF SPENT NUCLEAR FUEL

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ABSTRACT

The long-term safety of a KBS-3 type deep repository is based on a system of passive barriers with multiple safety functions, so that the degradation of one barrier does not substantially impair the overall performance of the disposal system. The repository is planned to be situated at a depth of about 500 m in granitic bedrock. From a tunnel system, deposition holes are bored in which copper canisters with spent nuclear fuel are emplaced and surrounded with bentonite clay. The tunnels will be backfilled. A basic requirement on geologic disposal of high-level radioactive waste is that the long-term safety of the repository should not be dependent on monitoring or maintenance by future generations.

The development of the Swedish repository system is based on a strategy of stepwise implementation. The deep repository will be built in two stages. In the first stage, approximately 10 % of the spent nuclear fuel will be emplaced after which the experience gained will be evaluated. Then follows disposal of the remaining spent fuel and closure of the repository. The strategy to start the disposal with a minor part of the whole programme and evaluate the result implies that retrieval has to be shown to be possible. However, this evaluation can cover only a short period in the long lifetime of a repository.

Through the various stages of the disposal of the spent fuel, normal monitoring for the operation and safe handling of the waste will be provided. Also monitoring for fire, flooding and handling accidents will be installed.

Monitoring devices may not be introduced in such a way that they jeopardise the safe performance of the repository. Hence, no instruments can be installed in the buffer around the canisters and the evolution of the buffer can only be studied in specially instrumented deposition holes, from which canisters are retrieved and disposed of permanently in a later stage. The rock can be instrumented and groundwater samples taken and analysed for long term monitoring, if desired, as long as the holes can be sealed once they are not used any longer.

During a period after closure, the repository area will be under institutional control. The length of this period has not been established in Sweden, nor has the need for specific monitoring been defined. Specific requirements on monitoring to comply with international requirements for safeguards are foreseen.

INTRODUCTION

The Swedish system of radioactive waste management (Figure 1) is based on the following fundamental principles [1]:

- Operational waste with short and medium half-life is disposed of as soon as possible after arising. A final repository, SFR, is in operation close to the Forsmark Power Plant

- Spent nuclear fuel is stored 30 to 40 years before being emplaced in a deep repository without reprocessing. A central interim storage facility, CLAB, is in operation close to the Oskarshamn Power Plant. The siting of the deep repository is in progress and disposal is planned to start around 2015.

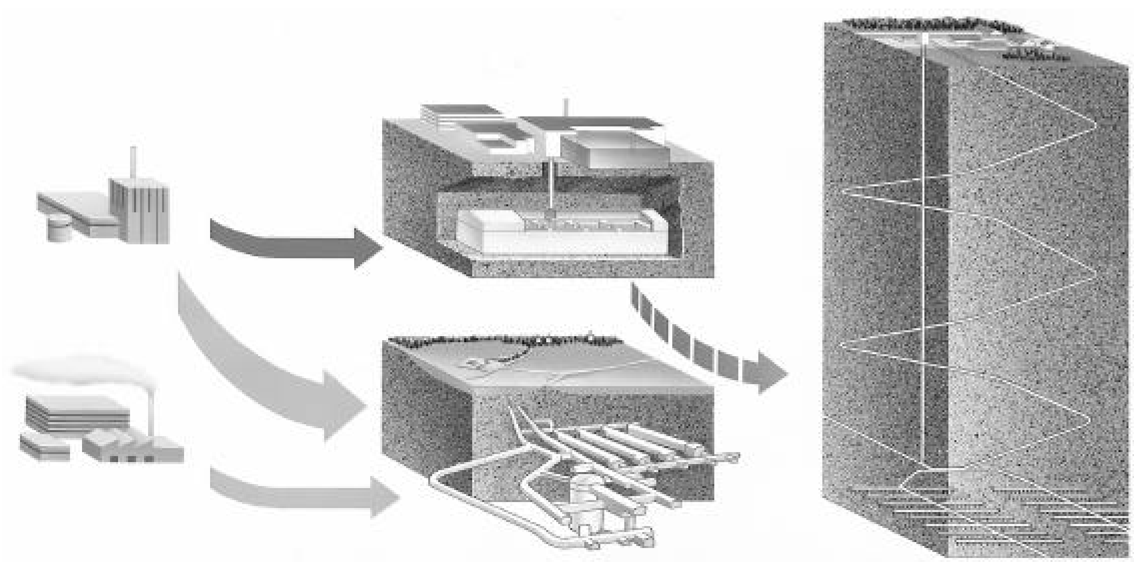

Fig. 1. Spent nuclear fu el (dark arrow) is stored in a central interim storage facility before disposal in the deep repository. Operational wastes from reactors and other sources (light arrows) are deposited in the SFR facility.

In order to achieve long-term safety, the disposal system is based on three safety levels – isolation, retention and dilution. First, **isolation** of the spent nuclear fuel from the biosphere is achieved by encapsulating the in long-lived copper canisters in a beneficial environment. In the next safety level, the repository has the function to **retain** and **retard** the transport of the radionuclides if the isolation is broken, thus allowing the radionuclides to decay before reaching humans and their environment. Thirdly, by proper site selection, transport pathways and **dilution** conditions in the biosphere can be influenced so that any radionuclides that escape will only reach man in low concentrations.

The long-term safety of a KBS-3 type deep repository is based on a system of passive barriers with multiple safety functions, so that the degradation of one barrier does not substantially impair the overall performance of the disposal system. The materials used in the repository are selected with a view to the possibility of using experience from nature to verify their long-term stability and performance in the repository. The repository is planned to be situated at a depth of about 500 m in granitic bedrock. From a tunnel system, deposition holes are bored in which copper canisters with spent nuclear fuel are emplaced and surrounded with bentonite clay. The tunnels will be backfilled.

STEPWISE IMPLEMETATION AND RETRIEVABILITY

The development of the Swedish repository system is based on a strategy of stepwise implementation. The first step comprised the development and assessment of the KBS-3 concept itself. The Swedish program is now in a phase of full-scale pilot testing of important system components and screening of potential repository sites. Characterisation of three potential repository sites is planned to start in 2002. This will be followed by a licence application for construction of the repository at one of these sites and an encapsulation plant. The deep repository will be built in two stages. In the first stage, approximately 10 % of the spent nuclear fuel, i.e. about 400 canisters, will be emplaced. This initial disposal period is planned to start around 2015 and last for about 5 years, after which the experience gained will be evaluated. Then follows disposal of the remaining spent fuel and closure of the repository.

Retrievability can be defined as 'a practical possibility to take back the radioactive waste deposited in a repository and to transfer it to a safe storage facility'. That is, it should be possible to locate and identify the waste packages, to retrieve them from the repository and to handle and transport them to another storage facility. Although the cost and effort needed is important for the practicality of retrieval, the term 'retrievability' has been used to indicate the **capability in principle** to retrieve the waste.

The strategy to start the disposal with a minor part of the whole programme and evaluate the result before any decisions are made on disposal of the rest of the fuel, implies that retrieval has to be shown to be possible. However, this evaluation can cover only a short period in the long lifetime of a repository, and will concentrate on the quality of transport and emplacement methods, excavation of backfill and freeing of the canister.

Retrievability during or after the full-scale disposal operation has only been discussed as a moral and ethical issue. Extensive discussions both in Sweden and internationally have resulted in the following Swedish view on deep geologic disposal:

1. The repository shall not be dependent for its long-term safety on monitoring or maintenance by future generations. This is not to say, however, that the repository cannot be monitored for a period after disposal of the waste or after the closure of the repository.

2. The repository shall not be designed in such a way that it unnecessarily impairs future attempts to change the repository or to retrieve the waste.

3. Information regarding the waste, the disposal system and the site should be preserved for the future as well as can reasonably be achieved.

No formal requirements on retrievability have yet been established in Sweden. The general view is that retrievability is good as long as it does not impair the capacity of the repository to meet the safety criteria. Furthermore, a sealed repository with proven retrievability is often considered safer than prolonged interim storage that requires surveillance and control over long times. The Nuclear Power Inspectorate intends to stipulate requirements for retrievability in its future regulations [2].

Technical aspects of retrieval

The present Swedish repository design has been developed with the intention to have a system with a very high and provable safety level, with no reliance on surveillance and maintenance and with no intention of retrieval. A consequence of this has been a repository with a system of engineered barriers of high structural integrity. However, the proposed design also offers a high degree of retrievability. Thus there is no contradiction between the planned disposal of the waste with no intention of retrieval, and retrievability (having the **capability** to retrieve).

The stepwise development of the repository, including an initial demonstration phase, implies that retrieval has to be shown to be possible. In the planned Deep Repository the spent nuclear fuel is in principle retrievable through all stages of the disposal process. The cost and effort involved in retrieval would vary through the different stages.

Reversibility of the deposition process is actually a part of the deposition process itself. Hence, if errors or mistakes are discovered in materials, the deposition process or in previous handling of canister and buffer materials the canisters may be retrieved shortly after deposition, the errors corrected and the canister deposited again. But once the canister has been embedded in the buffer and exposed to the swollen bentonite both freeing of the canister and gripping and lifting of it require handling sequences of a new process.

In a longer time perspective the conditions for retrievability differs quite a lot between the pre-closure and post closure periods. During the pre-closure period the access tunnels and shafts are open and any retrieval operation can start from underground. Once the decision has been taken to seal-off access tunnels and shafts, it is not likely that retrieval is seriously considered for a substantial period of time, for one thing because the sealing-off is such a definite activity that careful consideration will be paid to all aspects of the repository performance before it starts. A malfunction for example discovered by monitoring would change the situation, but as is argued later, there are no plausible events that in the foreseeable future would lead to release of radionuclides from the repository.

What may then cause an outcome leading to retrieval after the initial demonstration phase? Possible answers are that the disposal process is not mature enough for a regular operation, i.e. it is not possible to deposit canister after canister in the planned way, bentonite blocks or canisters are too likely to be damaged, the canisters are not centred in the hole as accurately as needed or water inflow is not possible to control in the planned way. It will be handling steps and practicalities that will be in focus. The major steps, if not the whole process, will have been demonstrated in the Äspö Hard Rock Laboratory or elsewhere prior to the start of disposal in the repository. The question of long-term performance is only going to be addressed indirectly as only the demands on the disposal process, set by the long-term performance requirements, are possible to include in the evaluation with respect to the relatively short time between disposal and evaluation.

One general question during the operational period is if the time for having easy access to the canister should be increased by delayed backfilling of tunnels. This issue was studied by SKB in 1995 with the outcome that some parameters with important impact on the long-term safety could be affected negatively by delayed backfilling, and the conclusion was backfilling of the tunnels should be made as soon as possible after disposal /3/. In perspective it is judged to be relatively simple to excavate backfill in case the canisters are going to be retrieved.

When the repository eventually is sealed-off the access to deposition tunnels and deposition holes becomes more difficult to open up again but never technically impossible, though costly. With proper radiation protection any condition of the canisters can be met.

Canister Retrieval Test In the Äspö HRL

One full-scale test is planned in order to develop a method and demonstrate retrieval capability before the first canister is deposited [4].

The test is located at the 420 m level in the Äspö HRL and will be a full size copy of a repository deposition holes, but without backfilling of the tunnel. Instead a plug is cast and anchored to the rock in the top of the hole. The test aims at demonstrating the method for freeing the canister from the grip of a swollen bentonite buffer, grip the canister and lift it up to the tunnel and place it in a radiation shield. The test set-up is illustrated in Figure 2. The installation has recently been completed and the heaters in the canister, which simulate the spent fuel, have been turned on. The artificial supply of water along the walls of the hole has started, and the time to full saturation is estimated to take 3 years, where after the retrieval test may be performed.

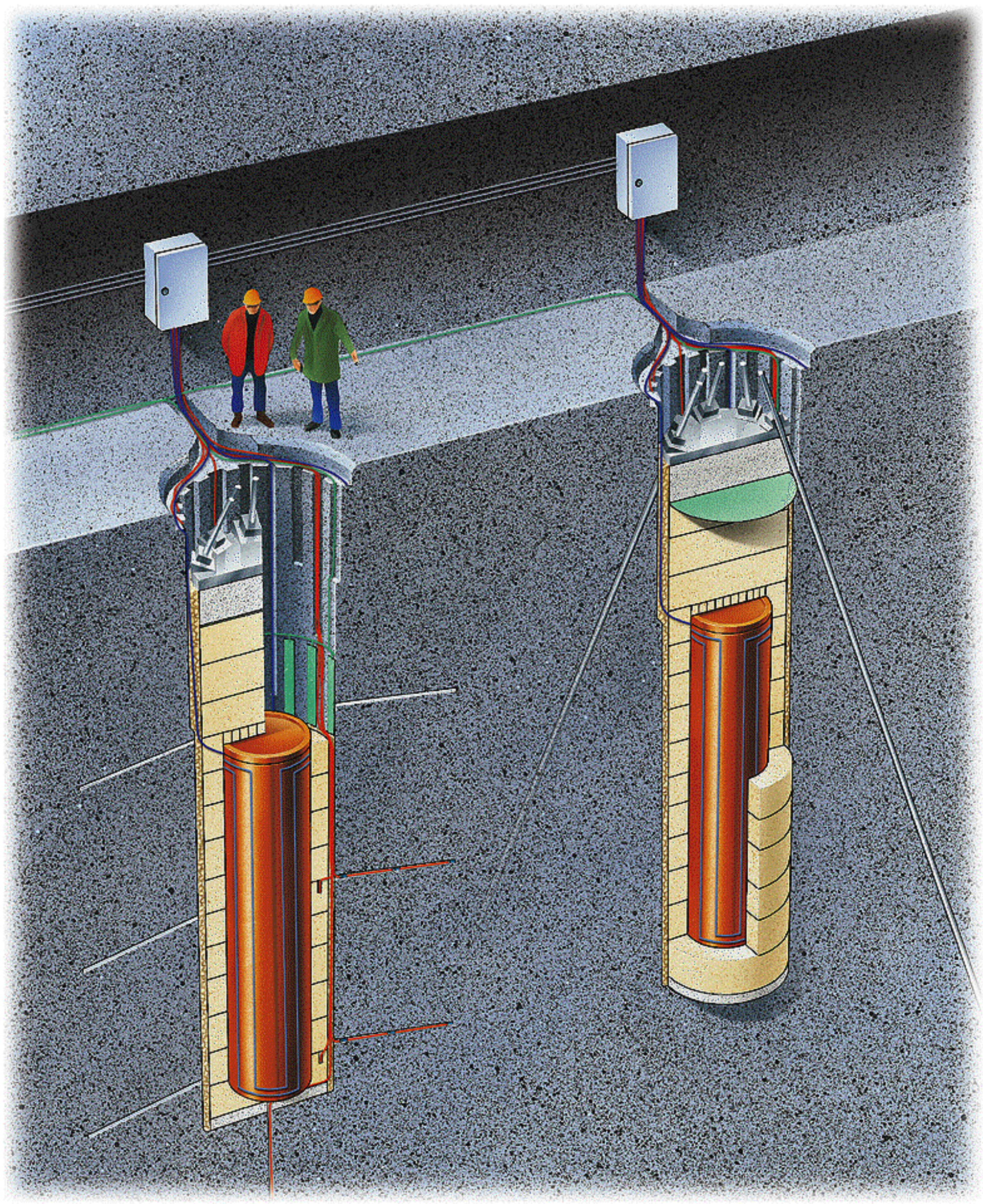

Fig. 2. Artist's view of the Canister Retrieval Test set-up. The picture to the left shows the holes for temperature measurement in the rock, while the picture to the right shows the cable bolts for the plug, the lead-through of cables in the top of the hole, permeable mats along the rock wall for artificial saturation and the sandwich structure of the plug (rubber mat, cast plug and steel lid).

MONITORING

Definition

Monitoring is generally considered important during repository development as it is expected to provide a basis for proceeding with the stepwise development. To distinguish monitoring from other measurements and observations that will be made in a repository we have defined it as repeated measurements or observations during a longer period of time, generally extending over several stages of repository development.

In this context we will only deal with measurements that help to evaluate the behaviour of components of the repository system or the impacts of the repository and its operation on the environment.

Need for monitoring

In the preliminary analysis made so far we have identified the following main motivations for monitoring in conjunction with repository development:

1. Establishment of baseline conditions, including seasonal variations, to be able to identify and evaluate the impacts of repository development and operation as well as post closure effects if any.

2. To strengthen understanding of system behaviour in order to support the safety case and allow testing of models and assumptions.

3. To determine radiological as well as non-radiological impacts on the environment from the repository.

4. To ensure that radiological and non-radiological work safety requirements are met during construction and operation.

5. To meet requirements on nuclear safeguards.

Prerequisites for monitoring

A basic requirement on geologic disposal of high-level radioactive waste is that the long-term safety of the repository should not be dependent on monitoring or maintenance by future generations. In a repository system where the safety is not dependent on long-term control and remedial actions, requirements for post closure monitoring are often regarded as controversial. However, if such a monitoring programme is implemented monitoring devices may not be introduced in such a way that they jeopardise the safe performance of the repository. This view is also held by The Swedish Nuclear Power Inspectorate [2].

Results from monitoring must meet very high demands on reliability as they will provide the basis for decisions on further repository development, remedial actions and possibly retrieval. It is not acceptable if erratic monitoring data result in, possibly comprehensive, unnecessary actions that cause serious environmental effects or hazards to workers. It is thus a requirement that it should be possible to check and calibrate monitoring instruments.

Establishment of Baseline Conditions

Characterisation of a repository site implies measurement of a large number of different parameters that are used to build a geoscientific model of the repository site. The geoscientific model as well as the associated site description and database are essential inputs to repository design and site-specific safety assessments [5]. It is envisaged that selected measurements made for characterisation purposes are repeated on regular occasions during the successive development stages of the repository. Hence, the site characterisation programme will provide the starting point for a monitoring program that possibly will continue even into the post-closure period.

Initially, during the surface based investigations specific measurement points will be selected for monitoring during the characterisation and construction phase of the repository. These measurements will provide input to the establishment of baseline conditions, characterisation of the site and the impact of repository construction on the environment. This strategy has been developed and applied at the Äspö HRL where a comprehensive monitoring programme of groundwater head and groundwater chemistry has been active for more than a decade. The monitoring program has also included measurements of environmental parameters such as precipitation, potential evapotranspiration, temperature, and sea level changes. The initial monitoring points from surface boreholes have during construction and operation of the facility successively been supplemented or replaced with monitoring points from underground boreholes. Data from the monitoring programme have been used to assess models of groundwater chemistry and flow and transport [4].

Monitoring and Long-Term Safety

The premises are that the spent fuel is encapsulated in a copper canister with a cast steel insert. This insert has a lid that is bolted on, not welded, but in a fashion that provides a tight seal for a long period of time [6]. In order to get any radioactive leakage except gamma and neutron radiation both the steel insert and the copper shell need to have defects not discovered during manufacturing and assembling, a very, very unlikely scenario. And still if this would be the case it takes a long time for water to penetrate and fill up the interior, dissolve radionuclides and emit them to the bentonite barrier outside. If also the time for the bentonite to saturate is taken into consideration and the resulting delay in transport of water into the canister and any dissolved species out from it, it will take generations before any dissolved radionuclide can reach the rock around the deposition hole. However, there are also gaseous radionuclides trapped in the zircaloy cladding that surrounds the spent fuel pellets. In case both the cladding and the canister are damaged the gas is released. One of the gases – iodine – can migrate relatively fast through the bentonite buffer. This is, however, also a very unlikely scenario. Consequently measurements of radioactivity will for generations to come have no real possibility to indicate any defect in the repository system.

It is thus not justified from a scientific point of view to monitor radionuclide content in or around the repository, as no radionuclides are possible to register and the measurements have no value as evidence for a safe repository. But such measurements may very well be justified from a public point of view, as measurements would show that everything is in good order.

Another possibility is to get evidence of the correctness of predictions made, i.e. that important processes are developing as expected. This is considered to be the basis for a monitoring programme with the objective of supporting the safety case and compliance with the radiological safety standards.

In the Swedish design, process parameters that have measurable transients during say the first 100 years (like temperature, re-saturation or pressure build-up in the bentonite) can be measured. Processes in the buffer and the surrounding rock are measured and studied in several of the experiments in the Äspö HRL, which provide a good enough understanding during the conditions prevailing in the underground laboratory. There will be small differences between the experiments and conditions in the actual repository, mainly related to radiation from the canisters and possibly different ground water composition. The consequences of these differences are thoroughly studied in surface laboratories, but are not possible to measure in the actual repository without having instruments in the buffer. Such instruments cannot be accepted as they would jeopardise the integrity of the buffer.

One possible way to verify compliance with findings in the Äspö HRL would be to set up a few instrumented deposition holes, which later are decommissioned, the canisters retrieved from the hole and deposited in new and final positions. With regard to the transparency of the data for the entire repository, such an undertaking would shed light on the compliance with the predicted long-term performance of the repository. Basically such monitoring could go on for twice the time the long-term monitoring of the same processes are planned to go on in the ÄHRL. This, however, does not change the relatively short time period of testing compared to the lifetime of the repository, but it would be the best that is possible to do.

At Äspö HRL two different tests are performed: the above mentioned Canister Retrieval Test with one canister, and the Prototype Repository with six canisters (see Figure 3) [4], thus providing some basis for the natural variation under similar conditions. The natural variation should as well be considered in the actual repository, which indicates that more than one canister position needs to be under observation in order to claim sufficient understanding, and that the monitoring goes on for such a long time that sufficient understanding is gained about the seasonal variations.

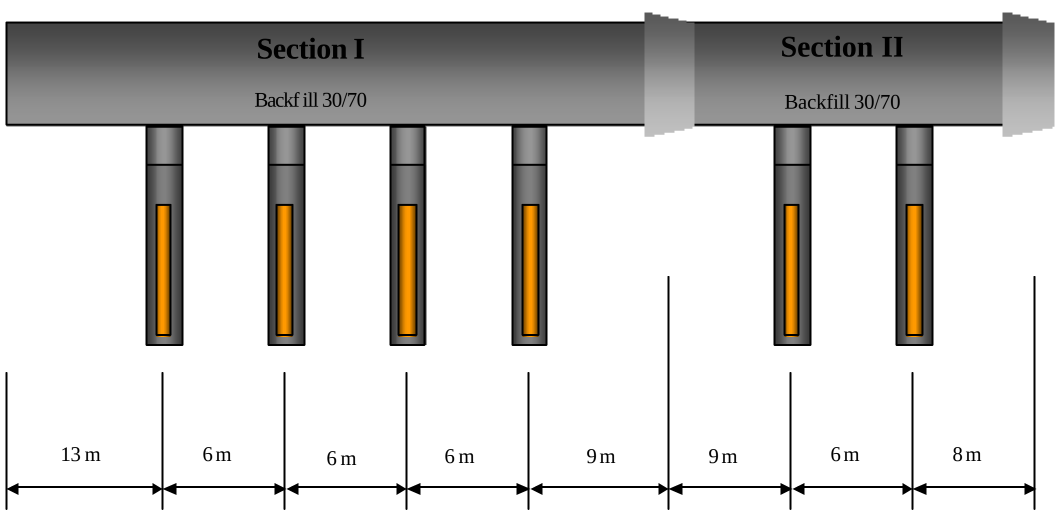

Fig. 3. Prototype Repository geometry.

The processes in the rock are somewhat easier to monitor, because the rock is stable and a hole would stand open for a long period of time, compared to a hole in bentonite, which swells and becomes closed. Therefore, rock monitoring can be arranged in many fashions and at many places, around temporarily installed holes or permanently deposited canisters. One demand is that the holes are effectively sealed after being used.

A guideline in the planning of instrumentation must be to have a possibility to calibrate or exchange an instrument that is not working well. This means that installations made underground cannot continue in operation after the closure of the repository, only surface based installations.

Some type of measurements can be carried out at a distance, like acoustic emission, seismic measurements, temperature and hydraulic regime. They benefit from the general information they can provide and are good supplements to the instruments positioned close to the disposal areas. It may also be possible to build up an understanding of the coupling between the readings in these instruments and the evolution in the near field of the repository.

Monitoring And Public Acceptance

Scientific understanding, know-how and practical tools for modelling and mathematical calculations are the instruments for describing the long-term safety. This is science and results can be controlled by experts and authorities. The understanding issue is dealt with intensively in all R&D work carried out and is well covered.

Trust from the public, however, brings about several associated questions, as the capability to show understanding is not necessarily coupled to the important questions for the long-term safety but also of being able to understand and predict the process and events that are actually seen. Here, monitoring of the repository could play an important role.

Monitoring of the emission levels of radioactivity or other substances in the environment, similar to the presently existing general environmental control of drinking water, can be done without affecting the repository system. The correlation between a registered signal and the repository performance is, however, weak. It must be recognised that the possibility to verify repository performance, can be an essential factor in the perception of repository safety, and thus important for public acceptance. Should equipment for post closure monitoring be introduced in the repository, their consequence on the safety must be evaluated, including an analysis of the possibility for equipment failure and false signals and the consequences of possible actions.

CONCLUSIONS

The strategy to start the disposal with a minor part of the whole programme and evaluate the result before any decisions are made on disposal of the rest of the fuel, implies that retrieval has to be shown to be possible. However, this evaluation can cover only a short period in the long lifetime of a repository, and will concentrate on the quality of transport and emplacement methods, excavation of backfill and freeing of the canister.

Retrieval of disposed canisters with spent fuel is judged to be technically feasible even after closure, though costs may become high.

Through the various stages of the disposal of the spent fuel, normal monitoring for the operation and safe handling of the waste will be provided. Also monitoring for fire, flooding and handling accidents will be undertaken.

Malfunction after disposal and backfilling of the tunnels - backfilling is made immediately after disposal - cannot be based on monitoring of the existence of radionuclides because the engineered barriers will not even in the worst case emit any radionuclides for generations. The monitoring may instead be focused on the evolution of thermal, hydrologic, mechanical, chemical and biological conditions in the buffer, backfill and rock. As no instruments can be installed in the buffer around the canisters the evolution of the buffer can only be studied in specially instrumented deposition holes, from which canisters are retrieved and disposed of permanently in a later stage.

The rock can be instrumented and groundwater samples taken and analysed for long term monitoring, if desired, as long as the holes can be sealed once they are not used any longer. This monitoring can be supplemented with systems covering whole rock blocks like acoustic emission. Experience on monitoring systems exist from Äspö HRL and the SFR final repository for LLW and MLW.

During a period after closure, the repository area will be under institutional control. The length of this period has not been established in Sweden, nor has the need for specific monitoring been defined. Specific requirements on monitoring to comply with international requirements for safeguards are foreseen.

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