RETRIEVAL IN A KBS-3 TYPE OF REPOSITORY – ONGOING WORK

Stig Pettersson and Christer Svemar, Swedish Nuclear Fuel and Waste Management Co.
SKB, Box 300, SE 572 95 Figeholm, Sweden
Rolf Sjöblom and Pal Kalbantner, ÅF-Energikonsult Stockholm AB.
Box 8133, 104 20, Stockholm, Sweden

ABSTRACT

In the Swedish system for radioactive waste management, the option of retrieval of canisters with spent nuclear fuel is regarded as an integral part of the design and licensing work. According to the present plans, about 400 canisters with spent nuclear fuel, corresponding to about 10 percent of the total number of canisters to be disposed, will be deposited in the first operation stage of the deep repository. After this first initial stage, the experience gained will be evaluated. This measure implies that the possibility to retrieve the deposit canisters has to be technically feasible and the canisters placed in an interim storage. The aim of the ongoing work, the *Canister Retrieval Test* at Äspö Hard Rock Laboratory, is to develop suitable methods and equipment for the freeing and removal of two full size canisters from their deposition holes with saturated buffer material with full swelling pressure against the canister. The conditioning and handling of the removed buffer material also is part of the work. The two canisters will be placed in the deposition holes in the spring of the year 2000 and the freeing and removing of the canisters will take place 3 to 5 years later. This will give reasonable time for completion of necessary feasibility and conceptual studies, design, construction, and testing of the equipment needed.

BACKGROUND AND DISPOSAL CONCEPT

The Swedish Radioactive Waste Management System (1, 2) is based on the following fundamental principles:

- Operational waste with short and medium half-life is disposed of as soon as possible after it has been generated. A Final Repository for Radioactive Operational Waste, SFR, is in operation since 1988. SFR is located close to the Forsmark Nuclear Power Plant site.
- Spent nuclear fuel is stored for 30 to 40 years before being emplaced in a deep repository without reprocessing. A Central Interim Storage Facility for Spent Nuclear Fuel, CLAB, is in operation since 1985. CLAB is located close to the Oskarshamn Nuclear Power Plant site. The encapsulation plant is planned to be co-located with CLAB. The siting process for the deep repository has started at six different locations/municipalities.

The long-term safety of the deep repository is based on passive multiple barriers so that the degradation of one barrier does not substantially impair the overall performance of the disposal system. One of the main considerations regarding the materials to be used in the repository is the feasibility of the verification of their long-term stability and performance in the repository that frequently is based on experience from nature. For the same reason, the thermal and chemical perturbations of the near field caused by the repository are designed to be limited in magnitude.

The KBS3-type of repository is planned to be located at a depth of about 500 m, depending on conditions at the selected site. In this repository, copper canisters containing the spent nuclear fuel, are deposited in bore holes in the tunnel floors and surrounded by highly compacted bentonite buffer. The tunnels are then backfilled with a mixture of bentonite and crushed rock. The principal design of barriers and the arrangement of the final repository are shown in Figure 1.

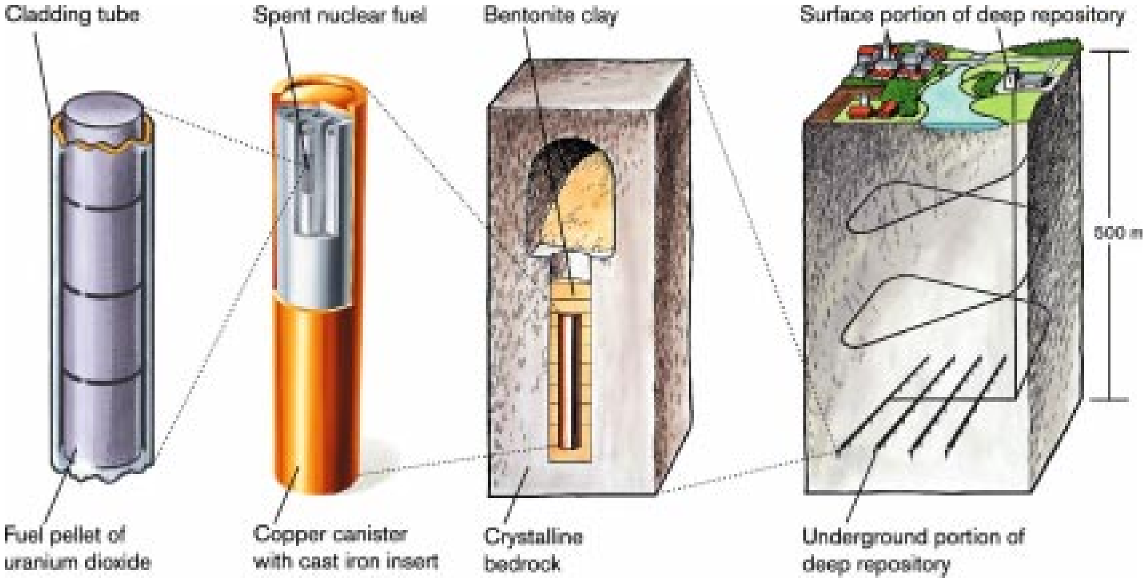

Figure 1. The spent fuel is encapsulated and deposited about 500 m down in the bedrock.

The present plan is to construct the deep repository in two stages. In the first stage, about 10 percent of the spent nuclear fuel, i.e. about 400 canisters, will be deposited. This initial disposal period is planned to start around the year 2015 and last for about 5 years, after which the experience gained will be evaluated.

If the result of the evaluation is that continued deposition is suitable and acceptable, which is the expectation, the entire repository will be built and the disposal activities continued until all waste has been deposited. The total quantity of spent nuclear fuel that is generated in the current Swedish nuclear power program is estimated to around 8,000 tons (figured as uranium metal) corresponding to approximately 4,000 canisters with spent nuclear fuel. If, on the other hand, an evaluation would lead to a decision to terminate deposition after the initial operation period, the option should be available to retrieve the deposited canisters and put them back in interim storage. In such a case, some, or possibly all, of the canisters will be surrounded by a saturated and swollen buffer material, which will hold the canisters in such a grip that they might not be pulled up without becoming damaged. Therefore, the canisters need to be freed from the surrounding bentonite before they are retracted from the deposition holes. Thus, a retrieval operation will comprise removal of the tunnel seal, the backfill material, the buffer material around the canister as well as removal of the canister itself. The latter operation may be carried out using the same type of equipment as for the emplacement of the canister. In the retrieval operation, the radiation levels of the canisters should be considered as well as the eventuality of contamination of the buffer material.

RETRIEVABILITY AND THE REPOSITORY SYSTEM

The repository system is being developed and designed to be at a very high and provable safety level and without reliance on surveillance and maintenance. Development of a repository system is a step-wise process, and much of the basic information regarding the repository performance will become available only as the steps are carried through. At each decision step in the repository development process, the ability to understand and to quantify the achievable safety has to be balanced against the commitments to the site or system that the step involves. Important in this balance and in decisionmaking under uncertainty, is the feasibility of taking a step back in the decision sequence. Here, the concept of retrievability can be extended into a generic one of reversibility of any action taken. Thus, during the operating phase, retrievability would correspond to the possibility to reverse the emplacement process. During the post closure phase, retrievability would correspond to the possibility to repossess the waste from the repository.

It can be inferred from the above that retrieval should be a realistic alternative for the repository system during its operation. However, no formal requirements on retrievability have yet been established in Sweden. Obviously, retrievability has a coupling to issues like non-proliferation and control of nuclear materials. It is a generally held view that allowing for retrievability must not impair long-term safety of the repository. Furthermore, a sealed repository with a proven retrievability is considered safer than a prolonged interim storage that would require surveillance and control over long times.

It is the opinion of SKB that no actions shall be taken during handling, and no arrangements shall be made that will unnecessarily hinder retrieval. SKB also holds the view that no actions shall be taken to improve the prospects of retrievability if this could impair the capacity of the repository with regard to compliance with the safety regulations.

PURPOSE AND SCOPE

The main aim of the ongoing work is to develop retrieval technology in the Swedish deep repository programme and to demonstrate to specialists as well as to the public that retrieval of canisters is technically feasible. The retrieval tests will be carried out after the buffer material has become fully saturated and its full swelling pressure has developed against the surface of the canister. The demonstration includes all systems and equipment necessary for safe removal of the buffer material, freeing of the canister, management of the by-products generated, and retraction of the canister from the deposition hole. The demonstration is planned to be carried out under simulated hot conditions and will include radiation shielding.

The objectives of the ongoing work includes the following:

- Selection of techniques for the freeing of the canister.
- Selection of techniques for determining the approximate position of the canister during the freeing operations.
- Determination of suitable operation parameters for the techniques selected together with verification of the efficiency of the technique selected under conceivable operating conditions.
- Selection of techniques for management of any by-products formed.
- Preparation of two deposition holes for full scale demonstrations.

Planned work includes the following:

- Development of methods and equipment for the freeing process in the demonstration experiments.
- Development of methods and equipment for the management of the by-products formed in the demonstration experiments.

- Execution of the demonstration activities.
- Adjustment of the methodology developed to actual operation in the deep repository.

It is planned that two different techniques will be tested for the removal of the buffer material.

THE RETRIEVAL PROCESS AND EQUIPMENT

Prerequisites for the Retrieval

As shown in Figure 1, the KBS-3 concept for final disposal features the deposition of canisters in holes in the floors of the deposition tunnels, with compacted bentonite between the canisters and the rock. The retrieval process may be separated into the following steps:

- Removal of tunnel backfill (bentonite and crushed rock) and buffer material (compacted bentonite) on top of canister.
- Measurement of the position of the canister.
- Cleaning of the grip - the grip in the lid of the canister used during the disposal is assumed to also be used for retrieval.
- Gripping of canister.
- Necessary removal of the buffer material around the canister and freeing of the canister.
- Lifting of canister into a radiation shield.
- Transfer of the canister to an interim storage.
- Conditioning and disposal of the removed buffer material.

It is anticipated that the equipment needed for retraction and handling of the canister will be similar or closely the same as that used for disposal. Thus, the development work focuses on the novel features of the freeing process, on the techniques for determining the position of the canister, and on the safe management of the removed buffer material.

A straight reversal of the emplacement operation is possible only in cases where the bentonite has remained dry. In general, it must be expected that the moistened and swollen bentonite holds the canister containing the spent nuclear fuel in a firm grip. A number of techniques have been studied (3) for the freeing of the canisters including *mechanical, hydrodynamical, thermal and electrical techniques*. In many cases, knowledge of the position of the canister is desired or needed. Therefore, different techniques for determination of the position of the canister have also been studied namely *mechanical, electromagnetic, thermal and acoustic techniques.* The techniques studied for freeing he canister are summarised below.

Selection of Techniques for Freeing the Canister

Initially, a number of methods were investigated, evaluated, and compared from a technical feasibility point of view. These were grouped into four main types according to the nature of the underlying techniques:

- Mechanical methods.
- Hydrodynamic methods.
- Thermal methods.
- Electrochemical methods.

The *mechanical methods* are based on dry mechanical excavation of the backfill and the bentonite. One unit is required for removal of the backfill and buffer on top of the canister and another unit for removal of the buffer around the canister. Drawbacks of these methods include complexity and hazard of canister damage.

Three different types of *hydrodynamic methods* were studied: water jet, water flushing, and disintegration of the bentonite with salt water. The principle of *water jet* is that a high speed water jet cuts into the backfill or the bentonite and loosens pieces or chips. In *water flushing*, the speed of the water is much lower than in the jet cutting method and the basic principle is to use a water gun that is directed towards the surface of the bentonite. In *disintegration*, a batch of a water solution with specific additives, e g a suitable salt, is flushed over the bentonite whereby a slurry it forms. The hydrodynamic methods have a drawback in that a by-product is formed in the form of a slurry that needs conditioning. The disintegration method, in particular, offers the advantage of simplicity.

The *thermal methods* studied include cooling of the surrounding bentonite, cooling of the canister, and heating of the canister. The basic principle is that bentonite and canister change volume when the temperature is changed, but in such a way that a slot may be opened between the canister and the bentonite. One major finding was that the slot formed between the bentonite and the rock, and not between the bentonite and the canister. Such a slot is of limited value since the interface surface is uneven and since removal of an entire canister/bentonite package may be anticipated.

The application of *electrotechnical methods* may involve at least four different possible effects:

- Destruction of the bentonite clay structure resulting in a decreased swelling pressure.
- Redistribution of water in the clay resulting in more water close to the canister.
- Drying of the bentonite due to heating resulting in shrinkage of bentonite.
- Drying of the bentonite due to gas production resulting in shrinkage of bentonite.

The methods investigated were found to have a number of drawbacks, including inefficiency.

In the overall comparison, the disintegration technique (the hydrodynamical-chemical technique) was assessed to the have highest potential with regard to the development of a safe, effective process for freeing the canister.

After the initial comparison, and after some subsequent work had been concluded, supplementary efforts were made in order to identify means of freeing the canister without removing all of the bentonite. In this selection process, the "pipe" method was assessed to have a high potential. In this method, a tool having a diameter larger than that of the canister is put on the bentonite surrounding the canister. The lower end of the cylindrical tool has an irregular pattern. Salt water is fed to the tool at various points, including the lower region of the tool. The tool is oscillated around its main axis, and at the same time pressed down onto the bentonite. In the process, bentonite is removed from the area under the tool and converted to a pumpable slurry through the action of the salt water.

The Reference Method for Freeing the Canister– Batch Disintegration

In the above described comparison of the different techniques for freeing, the chemical-hydrodynamical technique was identified to have a high potential for development of a process for freeing of the canister.

This technique requires little knowledge regarding the precise position of the canister in the deposition hole. Information on the position of the canister during the execution of the process may be obtained by ultrasonic techniques and/or dielectric techniques.

A realisation of this technique includes the following features. Water containing a few percent of sodium and/or calcium chloride is flushed over the bentonite surface, in which process the bentonite rapidly converts into slurry (4). The rate of the process increases with decreasing water content of the bentonite and with increasing salt content in the water with which the bentonite is flushed. Moreover, the rate of the process also increases with increasing salt content in the water with which the bentonite was saturated. It is assessed that the process is sufficiently efficient for all realistic parameter combinations and that a retrieval operation of one canister may take a few days in total, or less.

Dewatering of the slurry can be carried out by means of filter pressing, in which case the process is greatly promoted if a suitable additive is used. The additive may be a mechanical filter aid, an organic flocculent, or both.

FULL-SCALE TESTS AT THE ÄSPÖ HARD ROCK LABORATORY

Arrangements at the Test Site

The tunnel for the Canister Retrieval Test (CRT) is located at a depth of 420 m below sea level. The tunnel was excavated by applying conventional drill-and-blast techniques. Two full size deposition holes will be used and the distance between their centre lines is 6 m, which is the same distance as that planned for the final deep repository. The holes have been drilled to full size with a diameter of 1.75 m and a depth of approximately 8 m.

The two deposition holes for the CRT were bored using a small tunnel boring machine (TBM) converted for down hole boring with dry vacuum suction of the crushed rock. In total, 13 deposition holes were bored at Äspö from late 1998 to mid 1999. Six of these deposition holes will be used for the Prototype Repository. The remaining five deposition holes will be used for demonstration of the deposition technique and for testing of equipment to be used for handling and deposition of buffer material and canisters for the above - mentioned tests.

The canisters for the CRT will be full-scale copper/steel canisters of the same design as planned for the final deep repository, with one exception: the spent fuel is replaced by electrical heaters. The electrical heaters will simulate the decay power of spent nuclear fuel. Parameters of interest, and especially the water saturation, will be monitored using instrumentation on the canister surfaces as well as in the bentonite buffers.
The cast steel insert will be made in accordance with the BWR design, which has canals for 12 fuel assemblies. The weight with 12 Boiling Water Reactor (BWR) fuel assemblies is about 25 tonnes. The residual heat from the spent fuel assemblies is on the order of 1,700 Watts.

The buffer will be made of pre-fabricated bentonite blocks of highly compacted MX-80, i. e. Wyoming quality clay, and all slots will be filled with bentonite pellets. The target density of the saturated buffer is 2 tonnes/m^3, which corresponds to a swelling pressure of about 5 to 7 MPa. The buffer material is kept in place by a concrete plug on top that will be anchored to the tunnel floor by bolts as shown in Figure 2 below. The design of this plug is the same as the design that was applied in the Buffer Mass Test in the Stripa mine.

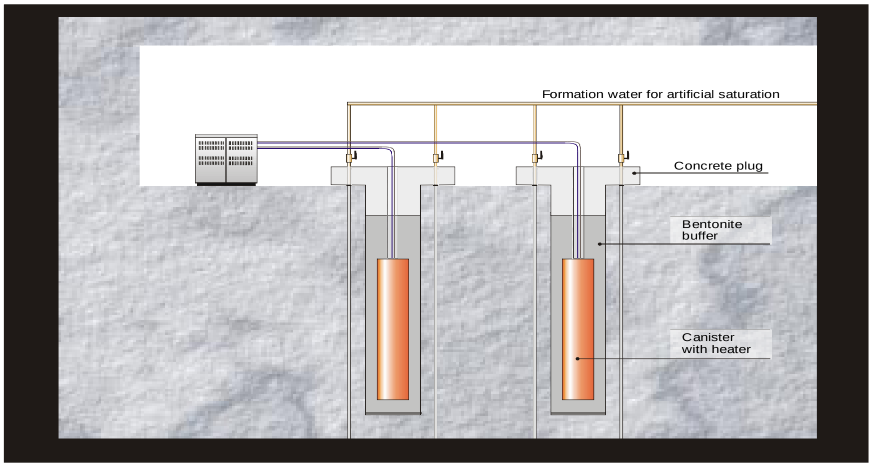

Figure 2. Arrangement of the test installation at Äspö

The rock mass in the test tunnel is very dry and the characterization work before and after drilling the deposition holes indicates that the water inflow to the test holes will be very low.

Consequently, the time for saturation of the buffer will very long, maybe tens of years. In order to be able to obtain saturated conditions relatively soon, a system for artificial saturation is thus deemed necessary. This system is planned to consist of permeable mats that are attached to the rock wall and connected to a water supply pipe. Saturation of the buffer is assumed to take 3 to 5 years even with the use of artificial saturation of the buffer material.

Canister retrieval

The actual CRT comprises the following steps: removal of the sealing plug; freeing of the canister by removing the bentonite material around the canister; and finally, gripping and lifting the canister to the tunnel and into a radiation shield. The reference method for freeing the canister is described above and the corresponding system for the actual operation will be designed in accordance with the illustration presented in Figure 3.

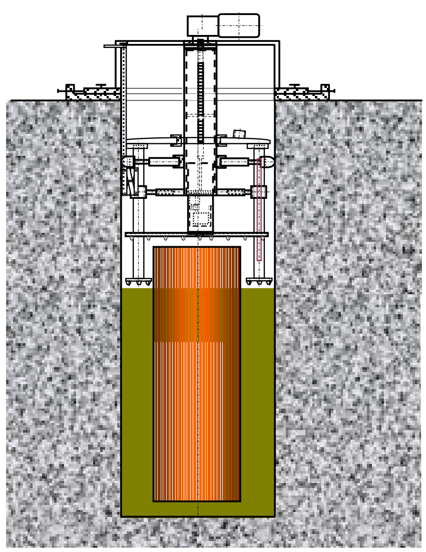

Figure 3. Disintegration of bentonite and flush removal of disintegrated layers

The canister gripping and lifting is preliminarily planned to be carried out using the deposition machine. This machine is otherwise utilized in the project on demonstration of deposition technique and used for placing canisters in deposition holes. This machine is equipped with a radiation shielding tube that is docked to the machine. When lifted, the canister is pulled directly into this shield. Altogether, the deposition machine including the radiation tube and canister weighs about 160 tonnes. The gripping device is the same as the one intended to be used during the deposition and consists of grippers that attach to the lid of the canister. For the deposition of these two canisters, a simplified deposition machine without radiation shielding will be used.

Conditioning of the removed buffer material

The application of the batch disintegration method implies that a bentonite slurry is generated during the removal of the buffer material. Pilot tests for treatment of this type of slurry have been performed during 1999 and a number of methods have been tested such as decanter, mechanical band filters, etc. The tentative conclusion is that mechanical band filters have shown a reasonable good performance and can be selected for further development work including design studies aimed at obtaining acceptable process parameters. The treatment process of the betonite slurry is illustrated in Figure 4.

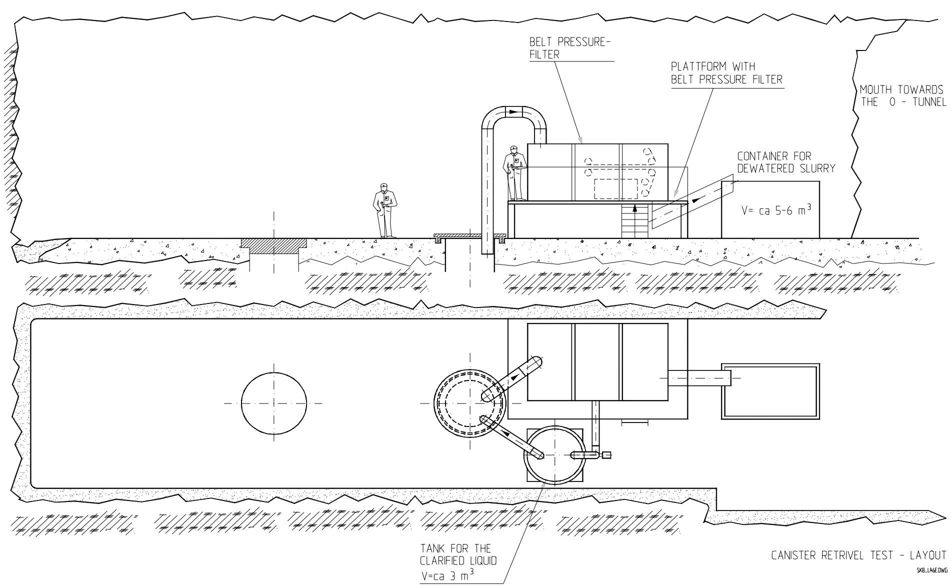

Figure 4 Principal arrangement of the bentonite slurry conditioning process

Time schedule

The bentonite for the buffer material has been prepared. The compaction of the bentonite buffer material was be carried out during November 1999 and January 2000. The construction work for the electrical heaters and canisters is in the final stage of completion. Moreover, the final characterisation of the deposition holes will be performed in January 2000. Purchase of necessary instrumentation for measuring different parameters such as temperature, saturation of the buffer material and also pore and total pressure in the buffer is in progress.

The bentonite buffer material and the two canisters will be placed in the deposition holes during the spring of 2000. The freeing and retrieval of the two canisters are planned to take place after 3 to 5 years after the emplacement.

CONCLUSIONS

The conclusions of the work carried out so far may be summarized as follows:

- Retrieval is technically feasible should it be required.
- Retrieval options is part of the SKB:s strategy to accommodate future technical and societal development.
- Promising retrieval techniques are under development and the chemical-hydrodynamic method is the preferred alternative but different parameter combinations must be studied further.
- Treatment/conditioning of the bentonite slurry is also technically feasible.
- Techniques for measuring the position of the canister during the execution of the freeing operation are available.

Summary of the planning work:

- An integrated program exists for the development and demonstration work needed for a retrieval system in an actual repository.
- Demonstration of retrieval operations will take place in the full scale in the Äspö Hard Rock Laboratory.
- The deposition holes have been drilled and the bentonite blocks have been manufactured.
- The CRT will commence in the beginning of the year 2000.
- Work is in progress on the process and equipment to be used in the retrieval operation.

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