# SKB studies on deep disposal and safety

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## Background

The Swedish nuclear waste management programme is aimed at deep geological disposal of unreprocessed spent nuclear fuel into the crystalline bedrock. Extensive research and development work has been performed since the 1970:ies. The disposal concept KBS-3 was first described in a safety report published 1983. Following national and international review of the KBS-3-study the Swedish Government decided in 1984 that it provided sufficient evidence for safe long-term disposal of spent nuclear fuel and gave permission for start-up of the last reactors in the Swedish nuclear programme. Since then, the KBS-concept has been further developed and partly modified in many details. Comprehensive safety studies have been published in 1992 and in 1999.

The present programme integrates safety research, technical development and a step-wise approach to siting and repository implementation. It has now reached the stage of full-scale inactive demonstration of disposal technologies and encapsulation methods in the SKB underground Äspö Hard Rock Laboratory and the Canister Laboratory in Oskarshamn. The siting programme is in its final phase with investigations going on at two sites – Forsmark and Oskarshamn – selected from the feasibility studies that were performed during the period 1993-2000. Final site-selection and licensing of a deep repository as well as of an encapsulation plant is planned to take place within the next 5-10 years. SKB has started the work of gradually preparing a comprehensive environmental impact statement (EIS) as a basis for the licensing application. Long-term safety modelling based on site-specific data will be a key component of the EIS.

## Disposal concept studies

The KBS-3 disposal concept as it has been developed over the last 25 years now is of the following design.

- Spent nuclear fuel is emplaced in 5 cm thick corrosion resistant copper canisters with a cast iron insert giving mechanical strength.
- The canisters are surrounded by 35 cm bentonite clay and deposited in individual deposition holes at a depth of 400-700 m in crystalline rock. Actual repository depth and layout will be dependent on site specific conditions.

This is the present reference design but ongoing RD&D-work can still result in modifications concerning for instance the thickness of copper canisters or detailed repository design and deposition methods.

## Canister design and encapsulation methods

The canister will be exposed to mechanical loads in the deep repository, caused by the pressure exerted by the groundwater and the swelling bentonite. Future ice ages or major rock movements can also give rise to mechanical stresses on the canisters. As long as the canisters are intact in the repository, all dispersal of radioactivity to the surrounding environment is prevented. If a penetration should occur in a canister, the other barriers will retard and reduce the dispersal of radionuclides. To achieve isolation, the canister must be leaktight on emplacement and be resistant to the chemical environment anticipated in the deep repository. They must withstand all known corrosion processes so that they can be expected to remain intact in the deep repository for at least 100,000 years. The canisters must also be designed so that there is no risk of criticality in connection with handling of the canister with fuel during the encapsulation process or in the long run in the final repository if water should enter the canister.

In the early KBS-3-design of 1983 a copper thickness of 10 cm was used and the inner space with spent fuel was to be filled with molten lead or possibly copper powder being solidified to a solid block through high-isostatic pressure techniques. Later it was considered unnecessarily complex to use a high-temperature process for encapsulation of the fuel and a more robust design based on prefabricated inserts was developed. Through more detailed studies on corrosion mechanisms and welding technologies it has been possible to reduce the copper thickness to 5 cm and the optimum thickness is now believed to be somewhere between 3-5 cm, still to be determined.

A key-issue concerning the KBS-3 canisters is the welding method to be used. A reliable technique for sealing of the copper canisters has to be developed and demonstrated on an industrial scale. The Canister Laboratory in the harbour of Oskarshamn, which is in operation since 1998, serves as a centre for development of encapsulation technology. A method employing electron beam welding of the copper lid is being developed and tested on an industrial scale in the laboratory. Methods for non-destructive testing of the weld are also being developed in order to be able to verify that canisters comply with the stipulated requirements concerning tightness and microstructure of welded seals. Results obtained show that electron beam welding is a feasible method for fabrication and sealing of copper canisters but further work is needed to improve the robustness and reliability of the welding process. Fully satisfactory results have not yet been obtained from the work of development of methods for non-destructive testing, this will require further efforts. SKB is also developing a friction stir welding method (FSW) as an alternative. Final selection of welding method is planned for 2005.

## Repository design and disposal technology

SKB has for many years been studying different alternatives of repository design and layout within the general concept of KBS-3. At present an in-depth evaluation is being made of the conventional vertical KBS-3 concept and a variant where the canisters are being placed horizontally in deposition tunnels. As site-investigation work now has been started work on adapting the layout and design of the deep repository to the conditions at the site has also begun.

SKB is also testing different backfill materials on a full scale at the Äspö HRL (Backfill and Plug Test). The main goals of the project are to test materials and methods for compaction of the backfill of tunnels and test the function and interaction with surrounding rock. The backfill is compacted in layers, with a technique developed in earlier tests. During the test, the sealing capacity of the backfill and the concrete plug will be measured. When the measurements are finished, the backfill will be removed for examination and analysis. Another objective is to develop and test methods for construction of concrete plugs for temporary sealing of deposition tunnels.

Since the deep repository is designed in such a way that it is possible to retrieve deposited canisters, it is necessary to develop and test the method for retrieval as well. The main goal for the test is to develop the method for freeing a canister from water-saturated and swollen bentonite. Two full-sized canisters will be placed in deposition holes and surrounded with bentonite. The canisters will be equipped with electric heaters and the bentonite blocks with some instrumentation. The deposition holes will be sealed with concrete plugs. The deposition holes will be left for 3–5 years to give the bentonite time to become saturated with water. During this time, equipment for freeing of canisters will be designed and manufactured. When the bentonite is saturated, the two test canisters will be freed and lifted out with the deposition machine.

## Studies on long-term safety

In preparation for the coming site investigations for siting of the deep repository, SKB presented in the end of 1999 a new safety report "SR 97 – Post-Closure Safety". The purpose of the SR97-report was to demonstrate by means of systematically conducted analysis that the performance of the repository complies with the acceptance criterion formulated by the Swedish regulatory authorities.

The overall conclusion of the analyses of the base scenario was that the copper canisters isolating capacity is not threatened by either the mechanical of chemical stresses to which it is subjected even over the long term including effects of glaciation. The SR-97 study also included scenarios on initial canister defects, earthquakes and human intrusion. The results and experiences are now being used in several ways:

- to further develop safety assessment methods
- to provide input for site-evaluation criteria and site-investigation strategies
- to prepare for the assessment work needed for licensing of a repository

The next major safety assessment for the deep repository will be conducted when the data from the site investigations are available. These analyses will comprise an important basis for selecting a site for a deep repository. The assessment will be appended to the application for a permit for siting and construction of the deep repository, planned for 2007. Before then, preliminary safety judgements will be made based on data from the initial site investigation phase. In conjunction with this, method development as regards e.g. scenario analyses, handling of uncertainties and risk calculations can also be reported and partially applied, along with new-found knowledge concerning canister and buffer. The account also comprises a basis for the safety assessment that will accompany the application for a permit for siting and construction of the encapsulation plant, planned for 2005. At later stages, assessments are planned that will comprise supporting material for applications for a permit to commission the repository and a permit for closure.