SWEDISH SPENT FUEL MANAGEMENT SYSTEMS, FACILITIES AND OPERATING EXPERIENCES

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Abstract

About 50 % of the electricity in Sweden is generated by means of nuclear power from 12 LWR reactors located at four sites and with a total capacity of 10 000 MW. The four utilities have jointly created SKB, the Swedish Nuclear Fuel and Waste Management Company, which has been given the mandate to manage the spent fuel and radioactive waste from its origin at the reactors to the final disposal.

SKB has developed a system for the safe handling of all kinds of radioactive waste from the Swedish nuclear power plants. The keystones now in operation of this system are a transport system, a central interim storage facility for spent nuclear fuel (CLAB), a final repository for short-lived, low and intermediate level waste (SFR). The remaining system components being planned are an encapsulation plant for spent nuclear fuel and a deep repository for encapsulated spent fuel and other long-lived radioactive wastes.

1. INTRODUCTION

About 50 % of the electricity in Sweden is generated by means of nuclear power from 12 reactors located at four sites and with a total capacity of 10 000 MW. Nine of the reactors are BWRs and three PWRs. The first commercial reactor was put in operation in 1972 and the latest in 1985. According to a decision by the Swedish Parliament in 1980 all reactors were to be phased out by the year 2010 at the latest. Until then about 8000 t of fuel would have been used and would have to be taken care of as spent nuclear fuel. Early 1997, however, three political parties in the Parliament reached an agreement on shutdown of one reactor in 1998 and another one in 2001, the latter provided that there is replacement power available. The year 2010, the year beyond which no reactor should be allowed to operate however is not an issue any longer. The Parliament voted in favor of the proposal in spring. The two reactors in question are those at Barsebäck in southern Sweden.

According to the Swedish spent fuel management programme the fuel from the Swedish reactors shall be taken care of within the country and be disposed of at about 500 m depth in the bedrock.

After unloading from the reactor core and a cooling period at the reactors the spent fuel is transported to a central interim storage facility where the fuel will remain for 30 - 40 years. During this period the radioactivity and the residual heat of the fuel will decay by about a factor of ten, thus making further handling and the final disposal simpler. The storage period will also provide time and flexibility for the elaboration of the details of these steps.

The responsibility for the management of the spent nuclear fuel, as well as for other radioactive residues from nuclear power production, lies with the operators of the nuclear power plants, i.e. the four nuclear utilities. The utilities have jointly created SKB, the Swedish Nuclear Fuel and Waste Management Company, which has been given the mandate to safely manage the spent fuel and radioactive waste from its origin at the reactors to the final disposal. The task of SKB is thus to plan, construct, own and operate the systems and facilities necessary for transportation, interim storage and final disposal.

Today the total irradiated fuel quantity amounts to about 4500 t including the fuel in the reactor cores.

2. SYSTEMS AND FACILITIES

SKB has developed a system that ensures the safe handling of all kinds of radioactive waste from the Swedish nuclear power plants for a long time period ahead. The keystones of this system (see Fig. 1) are:

- A transport system which has been in operation since 1983;
- A central interim storage facility for spent nuclear fuel, CLAB, in operation since 1985;
- A final repository for short-lived, low and intermediate level waste, SFR, in operation since 1988.

The remaining system components now being planned are:

- An encapsulation plant for spent nuclear fuel; and
- A deep disposal facility for encapsulated spent fuel and other long-lived radioactive wastes.

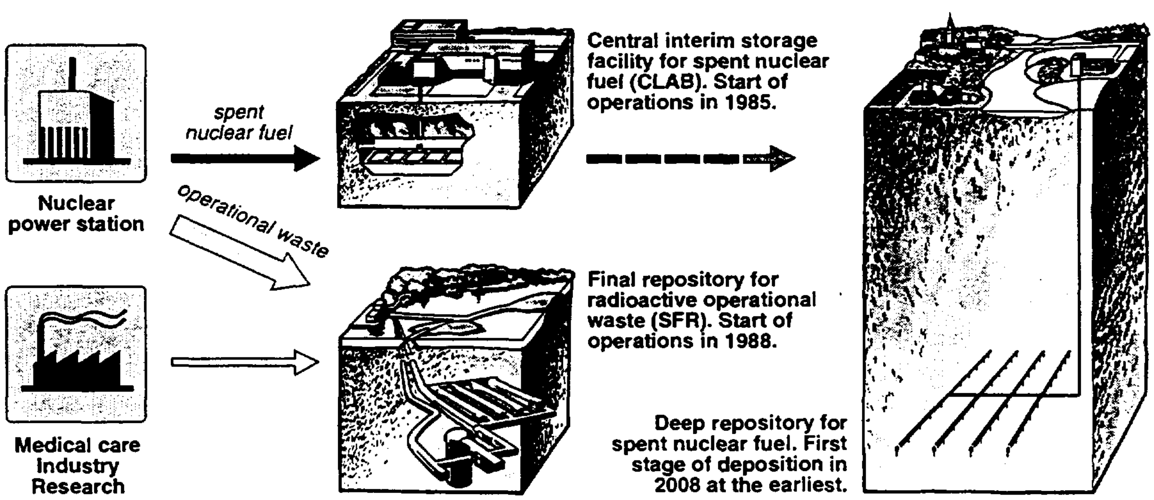


Figure 1. The Swedish system for radioactive waste management.

3. THE TRANSPORT SYSTEM

As all the nuclear power plants and CLAB are located on the coast and have their own harbors SKB has developed a sea transport system. This has many advantages, such as a high load capacity and low interference with other traffic. The system comprises a purpose built ship, the M/S Sigyn, 10 transport casks for spent fuel, 2 casks for spent core components and 5 terminal vehicles. The latter are used for the land transport from the reactor to the harbor and from the harbor to CLAB (Fig. 2).

M/S Sigyn is a roll on/roll off - lift on/lift off ship built for transports of radioactive waste. She has a dead-weight of 2000 t and can carry up to 10 transport casks for spent fuel. She has been designed with the most restrictive IMO rules concerning floatability after damage, similar to those for ships carrying chemicals in bulk. The ice breaking capability of the ship increases the availability in winter conditions. Another important safety factor is the most modern navigation equipment installed on board. However the ultimate safety of the transports depends on the 80 t heavy transport casks designed according to the IAEA regulations.

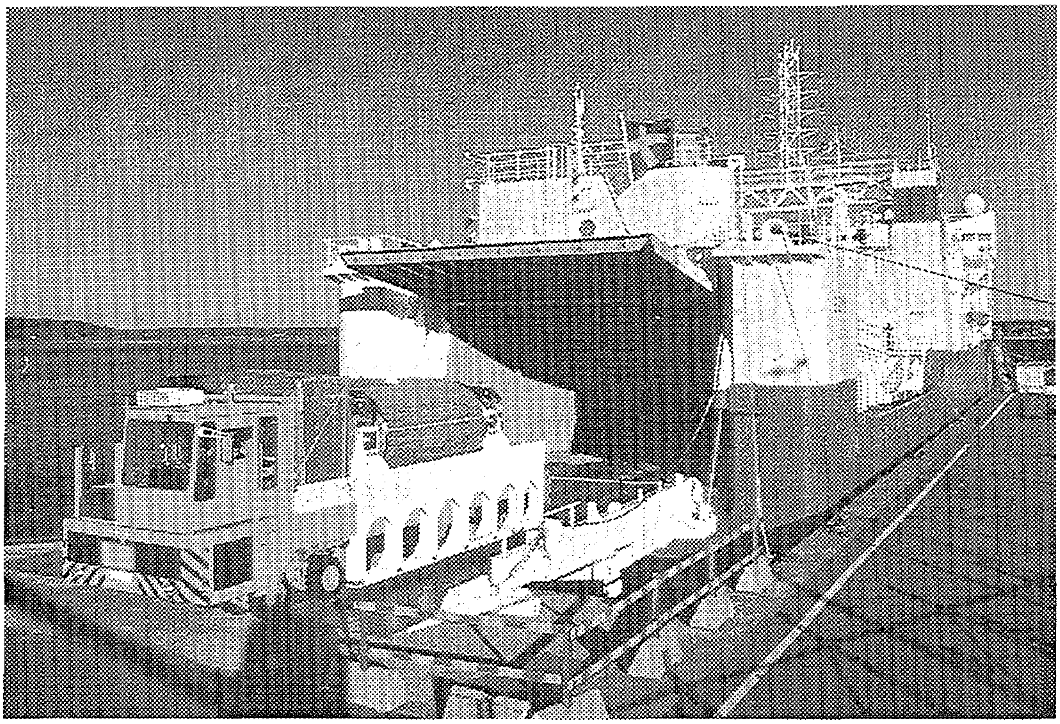


Figure 2. A fuel transport cask is being loaded on board the M/S Sigyn

The dry nitrogen filled cask cavity can accommodate 17 BWR or 7 PWR assemblies corresponding to 3 t of fuel. The cask is cooled by natural air convection around the 40 000 cooling fins on the cask outer surface. The cooling capacity allows fuel with a burnup of 55 000 MWd/tU and 9 months cooling time to be transported.

The dose rate criteria given by the transport regulations are, however, more limiting than the thermal ones, mainly due to the buildup of neutron emitters at high burnup. Transport of fuel assemblies with a burnup of 43 000 MWd/tU requires a cooling time of minimum 20 months. With higher burnup the necessary cooling time increases rapidly. Therefore a modification of two of the casks was performed in 1995 implying an increase of the thickness of the neutron absorbing resin on the cask surface at the cost of somewhat reduced thermal performance of the casks.

3.1. Operating experiences

In mid 1997 more than 900 fuel transport casks have been shipped to CLAB, corresponding to about 2700 t of uranium. In parallel around 80 casks with highly active core components, e.g. control rods, have been received at the facility. Typically 75 fuel casks are transported annually, corresponding to about 225 t of fuel.

The performance and availability of the system has been excellent. The fast and efficient handling and lashing operations for the casks on the ship have resulted in crew doses close to the those coming from the background radiation.

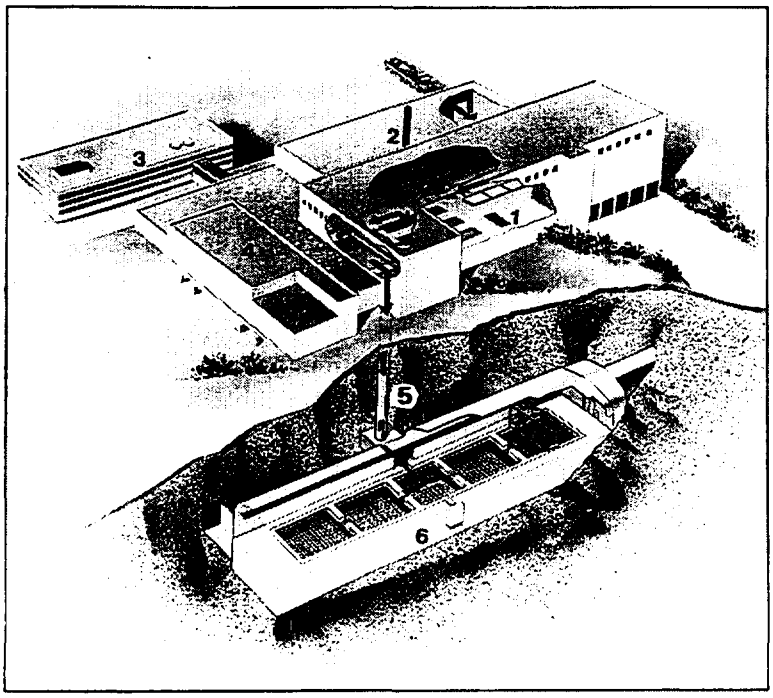
Another factor contributing to the good results is the detailed cask maintenance programme according to which a cask is brought in for maintenance after 15 transport cycles. Each transport cask has already gone through about 10 such overhauls. A more extensive maintenance is made after 60 cycles. The transport system is also used for transport of low and intermediate level waste to the SFR facility.

During the last 8 summers M/S Sigyn has been used as a floating exhibition for information to the public about the Swedish nuclear waste management system. In total almost 500 000 persons have visited the exhibition corresponding to about 6% of Sweden's population.

4. CENTRAL INTERIM STORAGE FOR SPENT FUEL, CLAB

CLAB, the Central Interim Storage Facility for Spent Nuclear Fuel, is located close to the Oskarshamn Nuclear Power Plant on the Swedish east coast. Operation started in 1985, and in June 1997 some 2700 t of fuel in about 900 casks had been received in addition to about 80 casks with activated core components, e.g. control rods.

CLAB comprises two principal parts, one above ground and one under ground. The main complex above ground is the receiving building, where the transport casks are received, prepared and unloaded. The unloading is performed under water. The storage section is located in a rock cavern, the roof of which is 25-30 m below the ground surface. Auxiliary systems, such as water cooling and purification, and electric power and control are located in buildings wall to wall to the receiving building (Fig. 3).



1. Receiving building

2. Auxiliary systems

3. Offices

4. Electrical building

5. Fuel elevator

6. Storage cavern

Figure 3. CLAB, Central Interim Storage Facility for Spent Fuel.

The receiving building has three receiving pool lines, two of which comprise two pools specially equipped for the standard TN17/2 transport casks. The third line can receive non-standard casks. Prior to unloading, the cask is provided with a metal skirt for protection against outside contamination and damage The skirt also makes it possible to apply very efficient water-cooling via the 40 000 cooling fins on the cask outside. After tests for fuel leakage and other preparatory measures including internal and external cooling the cask is transferred to one of the receiving pool lines, where the lid is removed so that the fuel assemblies can be lifted out one by one. Unloading - and all subsequent handling of the fuel assemblies - is performed under water with specialized handling machines. The two pools of each of the lines for standard casks are arranged in such a way that during unloading the outer surface of the cask skirt is in contact with non-contaminated water, while the fuel assemblies and the internals of the cask are in contact with contaminated water. After unloading from the cask the fuel assemblies are transferred directly to a storage canister, which subsequently serves as the handling unit in the facility. This greatly reduces the number of necessary handling operations.

The storage underground section consists of 4 storage pools in a 120 m long rock cavern. Each storage pool contains about 3000 m^3 of water and can hold 300 storage canisters. In the storage pools the canisters serve as storage racks. A fifth pool stands as a reserve in case of problems with one of the storage pools. The canisters are brought down to the rock cavern by means of the fuel elevator. The 40 m high elevator shaft itself is not water-filled but the canister is placed in the water filled elevator cage during the transfer.

The storage canisters are designed to maintain an adequate margin against criticality under normal and accident conditions. The original storage canisters can hold 16 BWR or 5 PWR fuel assemblies and have an internal structure made of normal stainless steel. As of 1992 the canister capacity has been increased to 25 BWR and 9 PWR fuel assemblies respectively, thereby enlarging the total storage capacity of CLAB from 3000 t of uranium to 5000 t within the existing space. The new canisters are successively being introduced in the facility. Two alternatives were considered to achieve the denser packing without exceeding the required reactivity margin of 5 percent units:

- the use of canisters with internal neutron absorbers, i.e. boronated steel or
- credit for burnup.

After a thorough analysis the boron option was chosen. This has the advantage that the control of the fuel assemblies at reception can be made much easier as it allows fresh fuel elements to be stored.

In the case with credit for burn up rather complicated verification measurements on the fuel assemblies at reception would have been necessary. It was further found that unexpectedly great uncertainties were coupled to the BWR fuel assemblies due to their axial burnup profile and void history. In order to cover all possible cases it would therefore have been necessary to apply a great reactivity penalty in the licensing calculations. Under these conditions it would not have been possible to store many of the already existing assemblies in the new canisters.

Other methods to increase the storage capacity were studied, e.g. new fixed storage racks, two tier storage and rod consolidation. These were however not feasible due to higher costs and/or technical reasons.

The present capacity of CLAB of about 5000 t of uranium covers the needs until around year 2004. CLAB must therefore be expanded by adding storage pools in a new rock cavern close to and parallel to the existing one. This was anticipated already during the construction of the facility and certain preparations were made to facilitate the building and the connection of the new cavern to the existing fuel containing pools. In June 1997 SKB submitted the application for the expansion to the government. According to current planning the construction of the second cavern will start in the second half of 1998.

4.1. Operating experiences

The performance of the plant has been excellent and due to improvements the operating costs have successively been reduced considerably. Some factors contributing to the reduction are improved operating procedures that has made it possible to unload casks in one shift instead of two and increased sharing of staff with the co-located reactors. A great saving was made possible by the installation of a heat recovery system allowing the residual power from the fuel in the storage pools to be used to heat the entire plant.

The residual power from the stored fuel to the water is regularly measured and compared to what should be expected from calculations. It has been observed that the measured value (with corrections for different factors) is lower than the calculated value. In the beginning a difference of as much as 40-50% between the two methods was observed. After correction for the power history of the individual fuel assemblies the difference has shrunk to about 20% which still is not satisfactory. In parallel calorimetric measurements are made in CLAB on individual BWR and PWR assemblies with different burn-ups and cooling times up to 15 years. In these cases the measured and calculated values correspond much better. The measurements and calculations continue and the definitive results will be reported in due time.

The activity release from the fuel has been much lower than anticipated. During the design phase, based on foreign experience, a high crud release was expected when the fuel is exposed to a certain thermal shock when the dry cask is filled with water. The experience at CLAB is, however, much better, which may to a great extent be attributed the small crud amount on the fuel which in turn is due to the good water chemistry and the materials used in the Swedish reactors. The activity release from the fuel in the pools is also low and dominated by ionic Co-60. This release is sensitive to temperature but up to now not to the amount of fuel in the pools. The low activity release in combination with an optimized management of the used filter resins has reduced the number of waste packages emanating from CLAB. The actual volumes are at least ten times lower than expected. Also the releases to the environment via water or air have been very low, less than a factor 1000 below the permissible limits.

The annual collective radiation dose to the staff and contractors has been between 50 and 135 mmanSv over the years, which is about 20 - 50 % of the dose originally calculated in the final safety report. In 1996 the collective dose was 50 mmanSv and the projection for 1997 is well below 100 mmanSv. The main part of the dose comes from plant refurbishment work and the handling, preparation and maintenance of the transport casks.

Normally the fuel from the Swedish reactors is transported to CLAB in the standard TN17/2 cask as mentioned above. Occasionally some non-standard casks have been received, e.g. with fuel from the old Swedish PHWR reactor at Ågesta and old MOX fuel from some German nuclear power plants. The latter as a result of an exchange of a small amount of fuel between Sweden and Germany. Also encapsulated residues from Post Irradiation Examination of LWR fuel at the Studsvik research centre are being shipped to CLAB. All these non-standard casks have been received in the third unloading pool without any problems.

5.THE DISPOSAL CANISTER AND THE ENCAPSULATION PLANT

The spent fuel will remain in CLAB for 30-40 years prior to encapsulation in a corrosion resistant canister and final disposal.

5.1. The disposal canister

The function of the canister is to provide adequate enclosure and radiation shielding of the fuel during handling before disposal and to provide an absolute barrier against radioactivity release for very long time thereafter. To remain tight the canister must sustain the mechanical and chemical environment in the repository (Figs. 4, 5).

The canister material most thoroughly studied in Sweden is copper which is almost unaffected in the reducing ground water found in the granite bedrock. The expected corrosion lifetime for a thick copper canister in such environment is millions of years and would thus isolate the fuel even beyond the lifetime of Pu-239. The canister consists of an inner steel body made of cast metal with channels for the fuel assemblies and a thick outer copper shell. The metal insert provides the necessary mechanical strength.

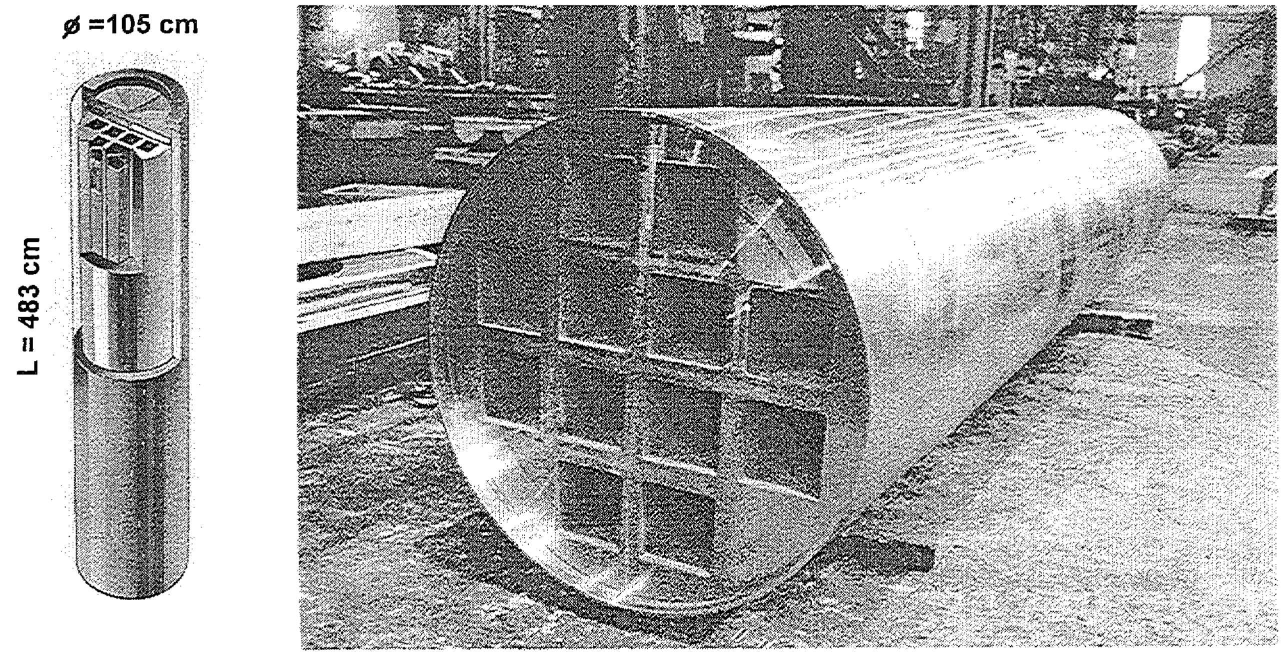


Figure 4. Disposal canister and cast canister insert.

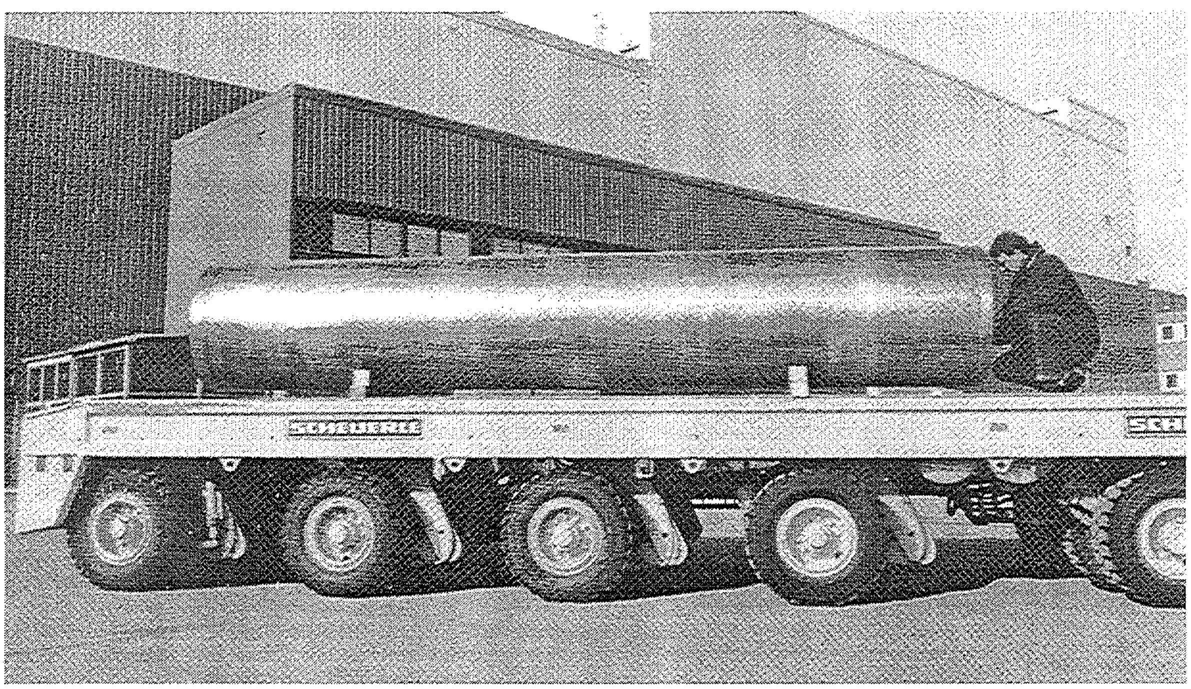


Figure 5. Full size test canister.

The canister will contain 12 BWR or 4 PWR fuel assemblies. The amount of fuel that can be loaded into the canister is limited by the maximum permissible temperature of the canister surface after disposal. This means that there is no advantage in consolidating the fuel assemblies. The outer diameter of the canister is 105 cm, the height 483 cm and the total weight approximately 25 t. For handling and transport an extra radiation shielding will be needed.

The filled canister must have a sufficient margin to criticality. Under normal conditions when the canister is dry this is not a problem. For certain accident scenarios in the repository or the encapsulation plant, however, it can be postulated that the canister will be water filled. If all the fuel assemblies in the canister are assumed to be fresh, a critical configuration may exist according to preliminary calculations. It will probably be necessary to take credit for the burnup of the fuel, and/or to control the reactivity by other means. As part of the checking of the fuel assemblies before placement in the canister it is therefore expected that a gamma measurement will be made. This measurement may also be utilized for the determination of the residual power and safeguards verification that may be necessary before the closing of the canister.

5.2. The encapsulation plant

The encapsulation plant is planned to be built adjacent to CLAB as a direct extension of the facility. The plant will incorporate the following main functions:

- Reception of storage canisters from CLAB via the existing fuel elevator;
- Selection of assemblies for encapsulation. Measurement;
- Filling of the disposal canister with fuel;
- Closing of the inner metal canister;
- Welding of the lid to the copper canister and non- destructive testing of the weld;
- Decontamination of filled canisters;
- Loading of canisters in transport casks for transport to the repository;
- Buffer storage for filled canisters.

In addition to the handling and process equipment necessary for these steps, auxiliary-, service- and control systems are required as well as facilities for the staff. Great advantage can be achieved by utilizing the existing corresponding systems etc. in CLAB.

A flexibility will be built in into the plant as a preparation for a later treatment of activated core components that are going to be disposed of in a deep repository as well.

A feasibility study of the plant was performed in 1993/94 and in June 1994 BNFL ltd., England, was selected by SKB as main contractor for the Basic Design of the encapsulation process. In parallel ABB Atom, Sweden, was contracted for the service and auxiliary systems and service areas. The Basic Design was completed in 1996 and will be the base for the Preliminary Safety Report. The licensing application is planned to be submitted to the authorities in 1999 at the earliest. The expected construction cost for the plant is around 2 billion SEK (approximately 250 million US$).

A crucial function in the encapsulation plant is the welding of the lid of the copper canister. This must be done remotely with a high accuracy, and in such a way that the result can afterwards be checked by non destructive testing.

The welding method preferred at present is electron beam welding at reduced atmospheric pressure. The development work has been going on for many years and by mid 1997 four full size test canisters have been fabricated.

The encapsulation is planned to be performed at a rate of one canister per working day. In order to be able to manufacture canisters on an industrial scale to meet this requirement SKB is building a canister laboratory for further development of final seal welding and non-destructive testing. The laboratory is located in the harbor of the town of Oskarshamn near the CLAB facility and the welding tests will start in spring 1998.

6. FINAL DISPOSAL IN A REPOSITORY

The safety of the repository is based on a "defense in depth"- concept in three levels. The first level is isolation of the radionuclides which is accomplished by the long-lived corrosion resistant canister. The second level is delay of the transfer of the radionuclides to the biosphere in case the isolation is broken. This delay is achieved by a very slow dissolution of the fuel and sorption and slow transport in the near and far field around the repository. The dispersion in the biosphere can be seen as the third level of the system. Based on this approach, the Swedish system for final disposal, according to current plans, has the following features: encapsulation of the spent fuel in the long-lived, corrosion resistant canister described in section 5 above, and disposal in the Swedish bedrock.

The disposal will be made at about 500 m depth. The canisters are deposited in holes drilled from the floors of drifts at a center to center distance of about 6 m. In the holes the canisters are surrounded by highly compacted bentonite which acts as a mechanical and chemical buffer material and prevents direct contact between flowing water and the canister. The tunnels and shafts are backfilled with a mixture of sand and bentonite (Fig. 6).

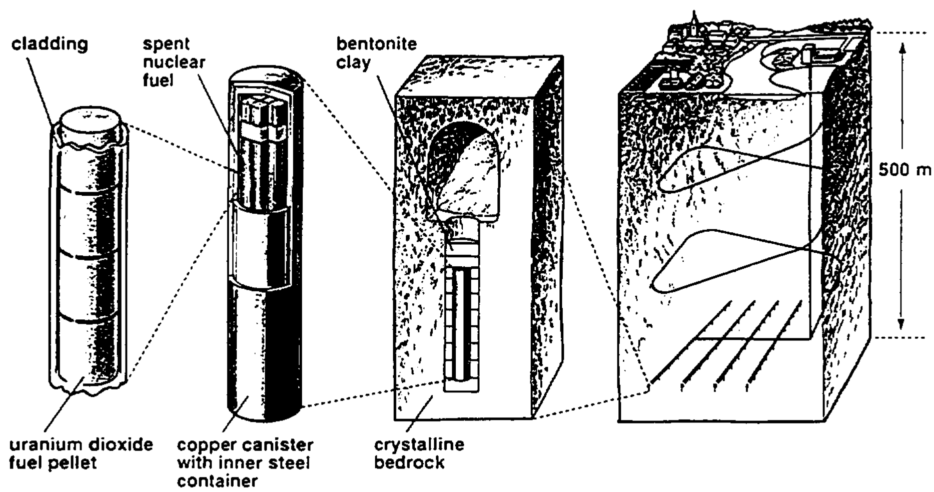


Figure 6. The canister in the deep repository.

The siting of a deep repository is politically sensitive in Sweden as in many other countries. From a technical point of view investigations have shown that there are many areas in Sweden were suitable geological conditions exist for a repository. Other factors such as transports, infrastructure, employment situation and political aspects will also be important for the siting.

To facilitate the siting and the public acceptance the disposal will be made stepwise. The first step will be the building the deep repository for a limited amount of spent fuel as a demonstration. When the demonstration deposition has been completed, the results will be evaluated before a decision is made whether or not to expand the facility to accommodate the total waste amount. This plan also makes it possible to consider whether the deposited fuel should be retrieved for alternative treatment. This procedure will make it possible to demonstrate the siting, licensing, design and construction, handling of the canisters and operation of the facility. For obvious reasons the long-term safety of the repository cannot be demonstrated. This must always be based on a technical-scientific assessment.

The start of the demonstration deposition could at the earliest be in the latter part of the next decade. Studies of the local conditions are in progress in some areas in co-operation with the local authorities. If the conditions are found suitable detailed site investigations will then be made at one site.