Encapsulation Plant for Nuclear Fuel Disposal

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ABSTRACT

This paper gives a general overview of the preliminary plans for the Finnish encapsulation plant for spent nuclear fuel. The encapsulation plant will be connected to the final repository.

INTRODUCTION

Direct disposal is selected as the spent nuclear fuel management strategy in Finland. Two Finnish nuclear power plants with a total of four operating units, two in Loviisa and two in Olkiluoto started their operation in 1977 and 1979 respectively. The final disposal of spent nuclear fuel is scheduled to start in 2020. Because the construction on the underground research facility is scheduled to start fairly soon, the encapsulation plant design has to be made in advance.

The spent fuel is transferred from the operating nuclear power plants to the interim spent fuel store at the existing sites of the operating nuclear power plants. The fuel will be stored from 20 up to 40 years. After storage, the spent fuel will be transported to the encapsulation plant, which is located at the one final disposal site, in Olkiluoto. In the facility, at the ground level, the fuel assemblies will be enclosed into fuel canisters, which will be transferred into the repository at a depth of about 500 meters in the bedrock. The fuel canisters will be placed into the final disposal holes, which are lined with bentonite blocks. Finally, the repository spaces will be filled permanently.

In the encapsulation plant, the spent fuel will be received and treated for final disposal. The fuel assemblies will be disassembled from the spent fuel casks and inserted into the fuel canisters. The gas atmosphere of the canister void will be changed to inert gas, the inner canister lid will be closed, and the outer canister's copper lid will be welded by electron beam (EB) welding. After the weld surface is machined, cleaned and inspected, the canister will be transferred into the buffer store and, after that, the canister will be transferred into the final repository. All work phases will be planned so that they can be performed safely without activity releases and without personnel doses.

The encapsulation process phases are shown in Figure 1, where the new canister storage and spent fuel receiving station is on the left, the hot cell in the center, and the welding cell, canister inspection and washing station on the right from the hot cell. The canister buffer store is on the right behind the labyrinth wall, and finally the canister lift, which will be used for transporting the canister to the final repository, [1].

RECEIPT OF SPENT FUEL AND STORAGE OF NEW CANISTERS

Spent fuel cask receiving and storing at the encapsulation plant

The casks are received in the spent fuel receiving and storing area. The transport casks will be used as a buffer store for spent fuel at the encapsulation plant. There is storage space for 5 casks. The casks can be also stored outdoors, if needed. The spent fuel receiving and storing area is shown in Figure 2.

The spent fuel casks will be transported by road transport trailers, at least the last leg of the journey. Before the road transport trailer is driven into the fuel receiving and storing area, the weather guard is rinsed. Rinsing is done with help of a pressure sprayer. After that, the collision shock absorbers of the transport cask are removed, and the cask is lifted either into the interim store in the receiving area or the cask can be lowered into the cask transfer corridor. The shock absorbers can be stored at one end of the receiving area. The cradle on the transport trailer is used as the tilting frame, when the transport cask is lifted in a vertical position. A bridge crane of 140 tons capacity for cask handling is provided in the cask receiving area.

The radiation level measurement and the contamination measurement are performed for the spent fuel casks in the cask receiving area. If the surface contamination exceeds the allowed limits, the cask is lowered into the cask transfer corridor for rinsing. The cask transfer corridor belongs to the controlled area, and the rinsing water is treated as active water.

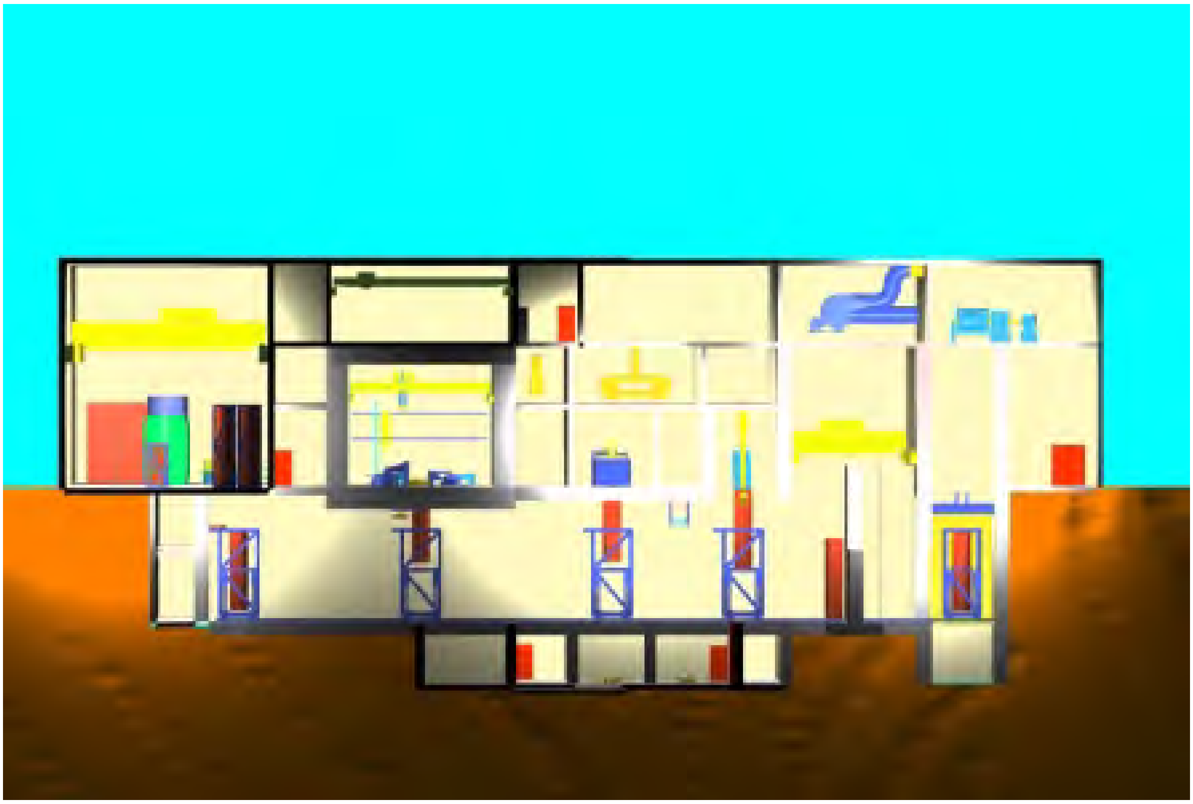

Fig. 1 Encapsulation phases, longitudinal section

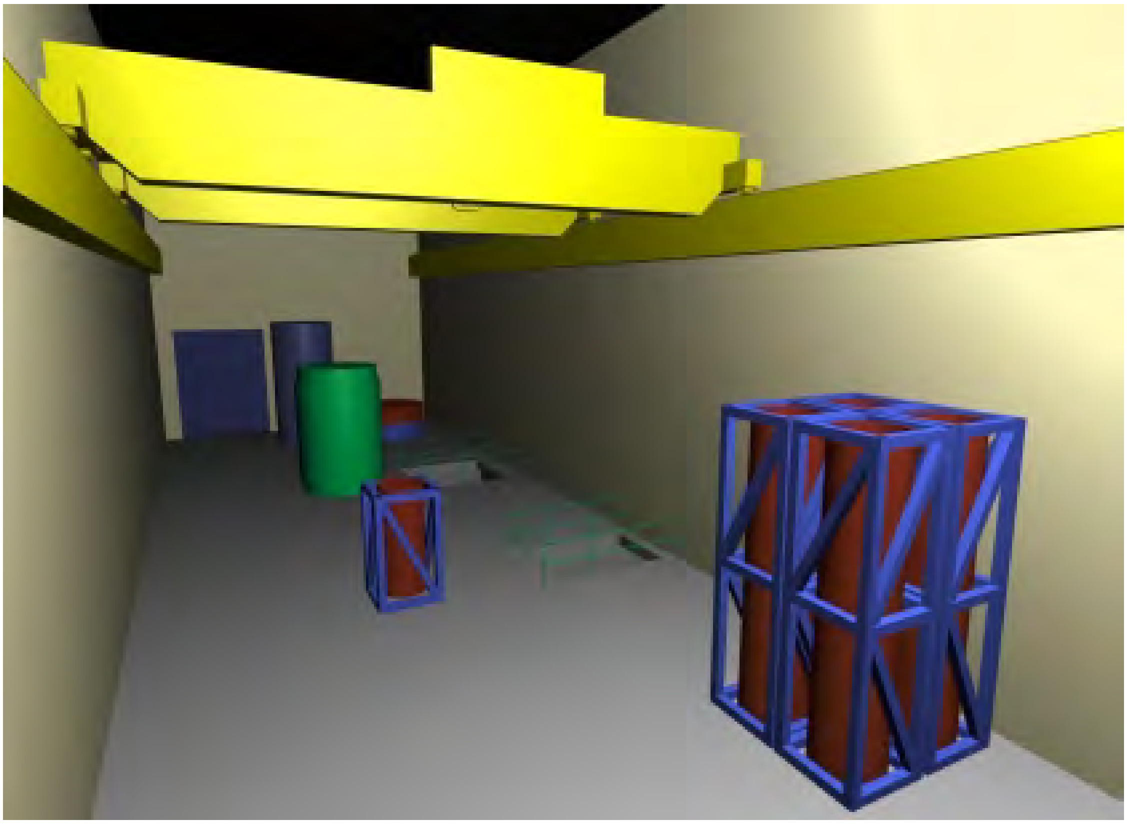

Fig. 2 Spent fuel cask receiving and new canister storage area

Spent fuel cask docking and opening of the cask lid

The cask is moved on rails under the hot cell, lifted upwards and docked tightly into the docking position in the hot cell, Figure 3. The cask is sealed with double expanding pressure air operated gaskets in the hot cell docking penetration. The internal covering hatch of the hot cell is opened, and the radiation protection lid of the cask is lifted inside the hot cell with help of a specific portal crane. The fuel assemblies can be removed from the transport cask with the fuel-handling machine. The fuel assemblies are removed from the spent fuel cask into the autoclave, and after that, into the fuel canister.

In the hot cell, the radiation protection lid of the spent fuel cask may become contaminated, in spite of the fact that a protective lid covers it. The contamination level of the radiation protection lid is measured. If contamination is identified, then the radiation protection lid is decontaminated by rinsing it with water in the cask transfer corridor.

The bolts of the radiation protection lid of the transport cask are reassembled, and the bolts are tightened. The outer protective lid of the transport cask is reassembled, and the bolts are tightened. The transport cask is lifted up to the cask receiving area. The transport cask is lifted on the trailer, the shock absorbers and the weather guard is reassembled. The transport cask is returned to the interim store, either to Loviisa or to Olkiluoto.

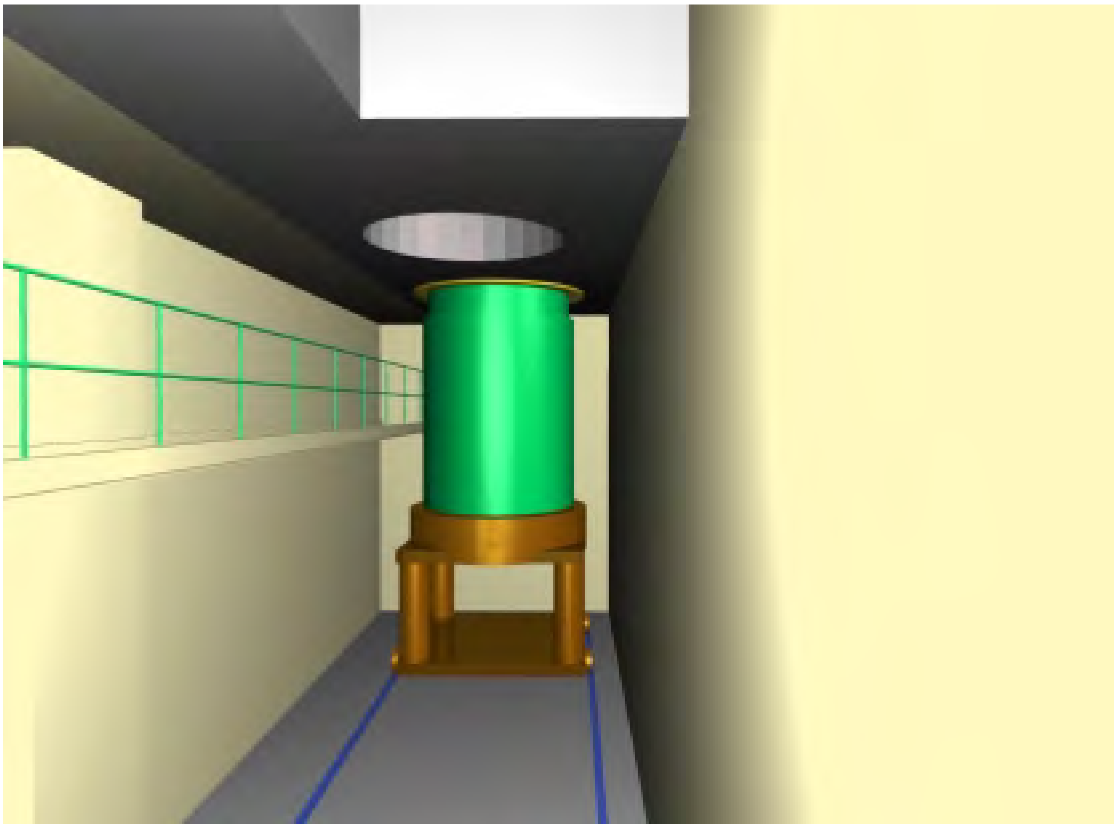

Fig. 3 Spent fuel cask docking with the hot cell

SPENT FUEL HANDLING IN THE HOT CELL

Hot cell arrangement

The arrangement in the hot cell is presented in Figure 4. In the back, the opened transport cask can be seen. Beside the opened cask, there is the other docking position for the other type of transport cask. The radiation protection lid is stored on place of the second docking position. The operating area of the portal crane covers the cask docking positions.

The fuel handling machine mast is on the left in the foreground. In the center, there are the autoclaves, which are used for drying the fuel assemblies. At the bottom of the picture, there is the docking position of the fuel canister.

The hot cell contains the fuel assembly gamma scanning device (and/or neutron detectors), which is embedded in the floor of the hot cell like the autoclaves. It is necessary to shield the measuring device against radiation from the open spent fuel cask or from the open fuel canister.

The systems, which need repair and maintenance, will be located outside of the hot cell, if possible. All operations in the hot cell are remote controlled. The hot cell is completely lined with a stainless steel liner. Provisions for possible operating incidents and accidents have been made. All equipment is designed to enable maintenance and repair.

Identification of fuel assemblies and γ-scanning

The fuel assemblies are lifted out, one by one, from the spent fuel cask. The fuel assemblies are identified by markings on the fuel grip. The markings are recorded and compared with the bookkeeping records. The gamma scanning measurement is performed for the fuel assemblies, and the measurement results are compared with the burn-up history, the cooling time and the activity level of the fuel assembly. The fuel canister loading management is done in such a way that older fuel assemblies are mixed with the younger cooled fuel assemblies, in order to keep the decay heat rate of each fuel canister constant and within the dimensioning calculations. The spent fuel transports are designed such that the heat-optimized encapsulation can be implemented.

Drying of fuel assemblies

The fuel cask is loaded with the fuel assemblies stored in the water pool of the interim store. The transport cask is kept full of water. The leaking fuel assemblies can contain water, because the fuel assemblies are stored in the interim store water pools.

The fuel assemblies are lifted from the transport cask via gamma scanning into the autoclave. There is one autoclave for the Loviisa plant fuel and another one for the Olkiluoto plant fuel. One autoclave has twelve storing positions for fuel assemblies. From the autoclaves, the fuel assemblies are transferred into the fuel canisters.

When wet transportation of the fuel is applied, the fuel assemblies have to be dried before the installation into the fuel canisters. The drying in the autoclaves takes place by elevating the temperature up to 120 ^{o}C and by vacuuming the autoclave. Air circulation and electric heaters are used to increase the temperature.

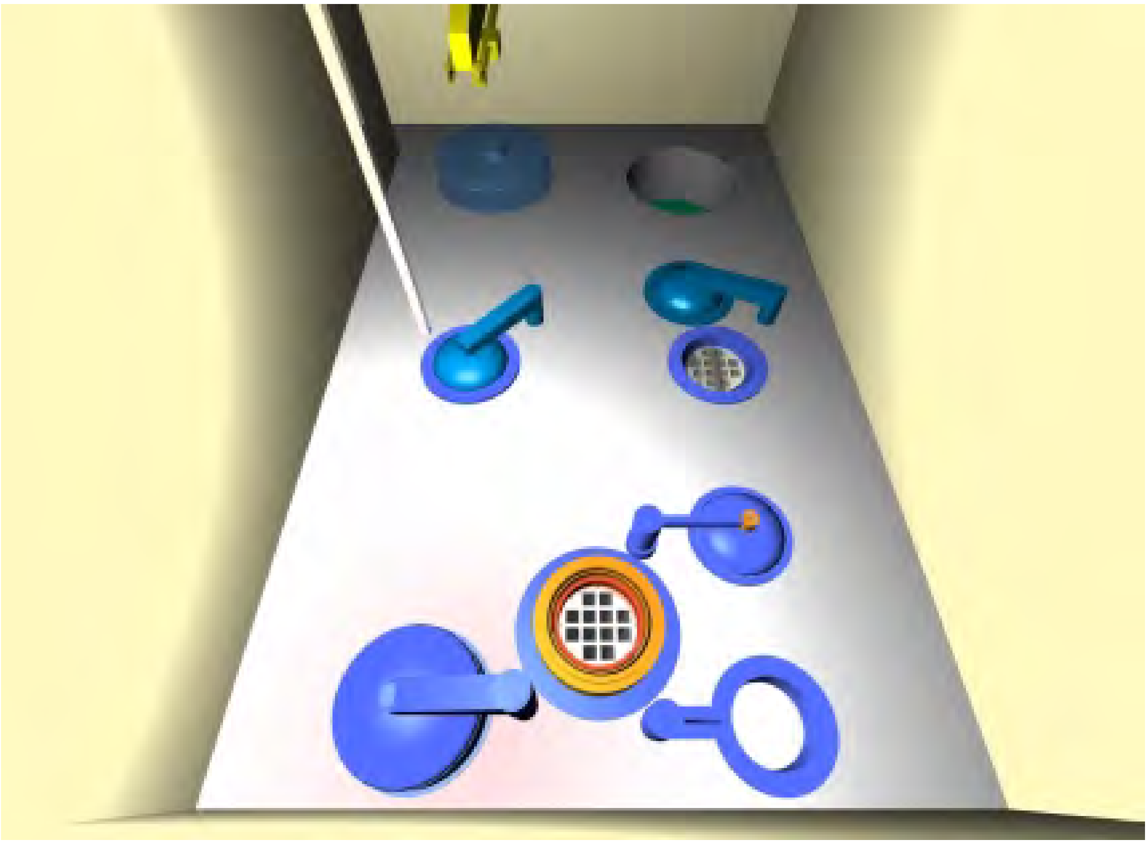

Fig. 4 Hot cell

Handling of leaking fuel assemblies

Leaking fuel assemblies are closed into the hermetically sealed casings before they are shipped to the encapsulation plant. A leaking fuel assembly is enclosed under water in a gas-tight casing. The fuel assembly having a gas-tight chamber is positioned at the encapsulation plant in the fuel canister, which has a special constructed inner structure. The leaking fuel assemblies of the Olkiluoto plant are assembled in a structure similar to the fuel assemblies; thus no special structures of inner canisters are needed.

If the fuel assembly starts to leak during the fuel shipment, it is inserted into the fuel canister in the standard manner, because provisions for leaking fuel assemblies have been made in the encapsulation plant system design.

Canister docking with the hot cell

The hot cell has one common docking position for the canisters of Loviisa and Olkiluoto plants. The docking penetration has a covering hatch, a hermetical atmosphere-changing cap for changing the air inside the canister with inert gas, and a protective cone, which is placed on the canister during the loading of the canister, in order to protect the seals, bolts and welding seam of the canister. The atmosphere-changing cap contains the nut drivers, which are used for screwing in and out the bolts of the inner steel lid of the canister. After the tightness of the junction has been assured, the internal covering hatch in the hot cell is opened. The copper lid of the canister remains outside, but the bolts of the steel lid are opened, and the lid is lifted inside the hot cell.

The copper canister lid is lifted onto the shelf beside the canister, after the canister has been placed on the trolley. All canister fittings are transported together with the canister, i.e. lids, inner lid sealing, bolts and nuts. The trolley and the transfer corridor are visualized in Figure 5. The trolley has a lifting and lowering mechanism for the canister. The trolley is moved into position under the hot cell, the canister is lifted upwards and docked tightly into its docking position. In this phase, the hot cell is closed with the covering hatch. The canister is lifted up and sealed with double expanding sealing of the covering hatch.

The nuts are opened with help of electrically or pneumatically driven nut drivers. The nuts of the inner canister lid are screwed out, and the inner lid is lifted inside the gas atmosphere-changing cap.

The inner canister lid with its gasket is transported together with the canister. The inner lid and the gasket are pre-installed in the workshop, however, the lid nuts are not yet tightened in this phase. The inner lid is moved with help of sleeved nuts. When the nuts are unscrewed, their flange lifts the lid. Each nut has its own nut wrench.

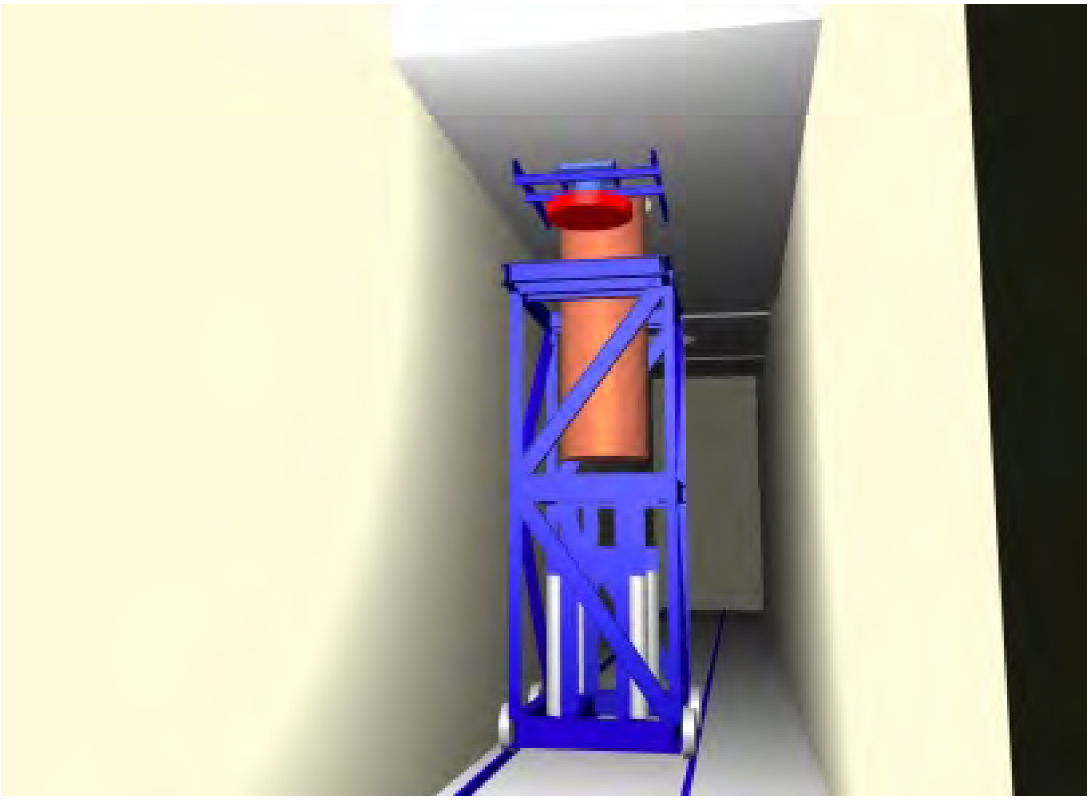

Fig. 5 Canister transfer corridor and the transfer trolley

The gasket surface shall be protected, while the fuel assemblies are installed into the fuel canister. Also the welding seam of the copper canister and the pin screws shall be protected at the same time. A protective cone is turned above the fuel canister. The cone will protect the welding seam of the copper canister, the pin screws of the inner canister and the gaskets of the inner canister. If crud falls on the cone, then crud is simply swept down into the fuel positions of the fuel canister.

Changing gas and tightening of the inner lid

After all twelve fuel assemblies have been installed into the fuel canister, the protective cone is removed. The sealing surfaces and the welding seams are checked for cleanliness and damages. If necessary, the sealing surfaces and welding seams are vacuumed. The gas atmosphere-changing cap is lowered on top of the canister. The expanding double sealing is used for tightening the canister in the cap.

After that, a vacuum is sucked inside the cap with help of a pipe coming from the canister transfer corridor. The cap is loaded with an about 10-ton pressure load from outside, because of the atmospheric pressure. After vacuuming, the canister is filled with inert gas, either helium or argon, up to the atmospheric pressure. When the canister is vacuumed, the extracted gas is led into the active ventilation system.

The inner lid inside the gas atmosphere-changing cap is lowered into its position, and all nuts are tightened simultaneously. For the inner lid alignment, two conical steering pins are arranged on the outer track. Corresponding holes are made in the inner lid. The pin screws will be at same level with the upper surface of the inner lid. The nut tightness is checked, based on the torque moment and the position of the nut. The top of the nut shall be at same level with the pin screw top. Open nuts are used for verifying visually the correct position.

Tightness test of the inner canister

The inner canister void (0.5 - 0.9 m^3) has been emptied from air and replaced with inert gas (He or Ar), before closing the steel lid. The inert gas pressure is equal to the atmospheric pressure. After the atmosphere change, the inner lid nuts are tightened. The leak-tightness can be verified by vacuuming again the gas atmosphere-changing cap and by checking potential inert gas leakage into the cap. There are gas snuffers for very small concentrations, at least for Helium.

After the inner lid tightness has been verified, the gas atmosphere-changing cap is lifted away from top of the canister, and the hot cell separation cap is lowered on top of the canister, and the seals are tightened against the docking penetration.

After that, the canister sealing to the hot cell docking penetration is loosened, and the canister can be lowered on the canister transfer trolley. Contamination of the surfaces and seals are checked and, in case of contamination, decontamination is performed.

In the canister transfer corridor, the copper lid trolley shelf is lifted on top of the fuel canister with help of the lid crane on the corridor roof, Figure 5. After that, the canister surface radiation rate will be about the same in all directions. No additional radiation shield is required on top of the canister.

The copper lid is provided with a groove for the gripping devices for canister handling, either lifting or lowering. When installed, the copper lid is inside the copper cylinder of the canister. The machined surfaces align the lid into the correct position. The fuel canister is transferred with help of a transfer trolley into the position in the welding chamber.

WELDING OF THE COPPER LID

Welding chamber

The EB-welding takes place in a vacuum chamber, which is a radiation-protected cylinder with lead glass windows. The welding chamber space is accessible during the welding of the canister lid. The welding chamber is so-called gamma area, where no particle radiation should exist. The welding can be visually controlled through the lead glass windows. The beam cannon for electron beam welding is in a vertical position at about half a meter's distance from the welding seam. The canister is rotating during welding.

In the welding chamber, provisions are made for performing a great number of test welds. Therefore accessibility into the welding chamber is important. The vacuum system and the electric systems of the electron beam-welding machine are located in the welding chamber.

The canister is lifted with help of a transfer trolley into the vacuum chamber so that the top of the canister is inside the vacuum chamber. The canister is sealed to the vacuum chamber penetration with expanding double sealing.

The clearance of the lid and the copper cylinder are checked. (No dead band is accepted). The edge of the copper cylinder is supported with help of the welding jig so that the welding seam will not open during welding. The jig is a clamping ring around the copper cylinder of the fuel canister.

The air in the vacuum chamber is evacuated. The volume of the vacuum chamber is minimized, so that vacuum can be created as fast as possible. The vacuum chamber pressure during welding is about $10^{-2} – 10^{-4}$ mbar. The vacuuming system is not necessary to be connected to the controlled ventilation system, because the tightness of the inner canister has been earlier confirmed. However, exhaust air is led into the controlled ventilation for safety. The copper lid is lightly grooved so that vacuum can also be created between the copper cylinder and the nodular cast iron insert.

The tolerance requirements depend on the welding direction. During welding, the canister is heated and thermally expanded. Positioning of the electron beam will compensate this thermal movement. Before the actual welding takes place, tag welds are made, by which the lid is partially welded into the copper cylinder. This procedure will prevent thermal distortion caused by heating during the actual welding. The actual welding of the lid will take some tens of minutes.

The first visual inspection of the weld can be performed during the actual welding through the lead glass windows or by camera in the vacuum chamber. In the visual inspection, the correct position of the weld is verified, and also the fact that there are no craters or other visible damage. If damage is identified, repair welding is performed immediately. After welding, the vacuum is inflated, the tightening to the vacuum chamber is loosened and the canister is lowered onto the transfer trolley.

Machining of the weld and weld inspections and cleaning of the canister

The canister transfer corridor is used for weld machining, cleaning and ultrasonic inspection. Also the X-ray tomographic inspection station is located in the canister transfer corridor. This method produces a strong radiation field. Tomographic inspection produces unique X-ray images from the welding seams of the canisters, and it can possibly be used as a “fingerprint” identifier in a later stage.

The ultrasonic inspection will be made as follows. First, the welding surface is machined. Then, a sleeve structure is fixed on top of the canister. The sleeve is filled with water. Moving multiplexed channel ultrasound detectors in the sleeve around the canister cylinder are used to inspect the welding seam. A weld is scanned from the side. The detectors are not in contact with the copper cylinder. If defects are identified, the canister is not to be returned yet for repair at this phase. After the inspection, the sleeve is drained and removed.

Dust and dirt on the canister surface are washed away, before the canister is shipped to the final repository. It is not question of actual decontamination, in case of the canister cleaning, because the copper cylinder cannot be contaminated at any work phase.

Handling of defective welding

If the weld work does not pass the inspection, the canister is returned for repair welding. The canister is moved to the electron beam welding station and, with a welding device, local re-melting will be performed in the area of defective welding. After repair welding, the inspections are repeated.

The canister is returned to the encapsulation line, if the weld cannot be successfully repaired. Cutting the copper cylinder from the side, just below the copper lid level, will open the canister lid. The milling station is in the same place as the copper lid crane. The crane is fastened onto the lid, and the upper part of the canister is cut off. The sealing of the hot cell docking station should be low enough so that the canister can be sealed to the hot cell penetration, in spite of that the upper part of canister has been cut off. The canister is docked again with the hot cell, and same operations are repeated, but in the opposite direction.

The canister is tightened onto the hot cell, and the separation lid of the hot cell is opened. The gas atmosphere-changing cap is lifted onto the canister, and the inner lid nuts are opened. The inner lid is lifted up, and the gas atmosphere-changing cap is turned away. The inner lid is inside the cap. Then the fuel assemblies can be removed with help of the fuel handling machine.

HANDLING OF FUEL CANISTERS

Canister transfer into the buffer store

After having passed the tomographic inspection, the accepted canisters are transferred into the canister buffer store for waiting to be transferred into the final repository. The bridge crane transfers the canisters from canister transfer corridor to the buffer store and further to the canister lift trolley through labyrinths. One side of the canister transfer trolley frame can be opened so that the canisters can be transferred without any high lifting.

The canister transfer trolley is equipped with electrically driven machinery for movement and electrically driven screw machinery for canister lifting. Against failures in the transfer mechanism, the trolley is provided with a winch mechanism so that a jammed trolley can be towed to the place it can be repaired, for example, to a location in the buffer store. The fuel canister is lifted into the buffer store and, after that, the trolley is accessible. Also when new canisters are loaded on the transfer trolley, the operating personnel can be in situ, for manual operations and controls.

Canister transfer from the buffer store into the canister lift

The fuel canister is transferred into a vertical position through a labyrinth from the canister buffer store onto the canister lift trolley.

The canister lift trolley is similar to the trolley in the canister transfer corridor. It needs also a lifting mechanism in order to prevent the canister from falling at the repository level, when the canister is picked up into the canister transfer vehicle. Finally, the canister is moved into the lift and lowered into the underground repository.

The payload of the canister lift, including the lift car, is minimized. The weight of the loaded fuel canister is about 25 tons, and the trolley weight is about 5 tons, totaling 30 tons.

The lift car can be driven through with the trolley. The lift car floor has rails and two doors at both ends of the car. In the encapsulation plant and at the final repository level, there are two lift stops. The fuel canister lift trolley is driven into the lift car with the fuel canister on it. At the final repository level, the canister is driven out to the canister docking station, where the canister transfer vehicle can pick up the fuel canister.

Direct radiation from the lift shaft is prevented by means of a canister lift entrance room, when transporting the fuel canisters into the final repository.

SUMMARY AND CONCLUSION

Direct disposal is the strategy applied on spent nuclear fuel management in Finland. Before disposal, the fuel assemblies are closed into composite canisters, which have a nodular cast iron insert and a 50-mm-thick copper sleeve. A facility has been designed for operations needed for the fuel encapsulation, starting from the fuel assemblies' removal from the spent fuel cask to the shipment of the ready fuel canisters to the final repository.

The most demanding phases in the encapsulation process are the welding of the copper canister lid and the weld inspection. Electron beam welding is used for fixing the canister lid.

The encapsulation process is feasible, but a lot of detailed designs are still required.

REFERENCES

1. Kukkola, T., Encapsulation Plant Description, Posiva Working Report 2000-08, July 2000.