18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-W01-1

FINNISH CONCEPT FOR SPENT NUCLEAR FUEL DISPOSAL

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ABSTRACT

In Finland, the spent nuclear fuel will be emplaced in the bedrock at a target depth interval of 400-500 metres. Posiva Oy is the company responsible for high active nuclear waste management in Finland. Currently, an ONKALO URL (Underground Research Laboratory) has been under excavation since summer 2004 at the selected final disposal site. Construction of the actual final disposal facility will begin in early 2010´s and the facility shall be operational in 2020.

According to the present plans, the final disposal will be implemented in a way that fuel bundles as a whole will be sealed in canisters that are made of nodular cast iron, enclosed in a corrosion resistant, 50 mm thick copper shell. The canisters will be emplaced in holes drilled at the bottom of the tunnels excavated in the bedrock. The canisters are surrounded with compacted bentonite clay. Deep repository prevents unintentional human intrusion into the final disposal facility. The disposal facility is described in more detail by Tanskanen & Palmu (2003). The Finnish concept is nearly similar to the Swedish concept introduced by Swedish Nuclear Fuel and Waste Management Co (SKB). Posiva and SKB are in close co-operation in developing of the concept and technology.

Keywords: spent nuclear fuel disposal, encapsulation, disposal facility, KBS-3 concept

1. INTRODUCTION

In Finland, there are two companies producing electricity using nuclear power, Fortum Power and Heat Oy (Fortum) and Teollisuuden Voima Oy (TVO). Under the Nuclear Energy Act, Fortum and TVO are responsible for the safe management of the waste and for all associated expenses. Each company is responsible for processing and disposal of its own low and medium level radioactive waste, as well as for all operations included in the decommissioning of the plants. Posiva Oy, a joint company owned by Fortum and TVO, is responsible for research and technological development concerning spent fuel disposal, as well as construction and operation of the disposal facility. Under the Nuclear Energy Act (1987) and in compliance with Government decisions, all existing and future spent nuclear fuel from the Loviisa and Olkiluoto plants is to be disposed of in the Finnish bedrock. Parliament approved in 2001 the Government’s Decision in Principle on Posiva’s application for a construction licence for a disposal facility for spent.

When providing for disposal to be carried out in Finland, the starting point is that spent fuel removed from the reactor shall be stored in interim stores until the disposal operation starts in 2020. Before 2020 the spent fuel will be temporarily stored in intermediate stores in the plant areas.

TVO and Fortum must be prepared to submit clarifications and designs required for the construction licence for a spent fuel disposal facility by the end of 2012, on the basis of which the disposal can take place in 2020.

2. STARTING POINT FOR DESIGN

2.1 Safety Concept for Disposal

Posiva's repository design is based on the KBS-3 concept, which was developed by the Swedish SKB. The disposal concept and the repository are based on the multi-barrier principle, in which several engineered barriers support one another so that insufficiency in the performance of one barrier (or subsystem) does not jeopardize the long-term safety of the disposal system.

The safety concept starts from the premise that the repository materials are available in nature. Safety is achieved under the natural conditions of the deep bedrock during the construction of the repository, as well as under future conditions caused by climatic change. Furthermore, the repository design leans on simple subsystems, on the coherent results of a long-term programme of research and on the knowledge that proven technology for implementing the repository is available. The safety concept reflects the view of how long-term safety can be achieved, taking into account existing constraints related to disposal and by using technical solutions that meet the requirements imposed by Posiva.

2.1.1 Long-term Safety Issues

The safety concept is based on long-term isolation and the disposal system is planned to retain radioactive releases within the geosphere and the biosphere for at least 100 000 years. The underground repository is built at a depth of 400-500 meters. The spent fuel assemblies are placed into copper canisters. Before the canister is emplaced into a deposition hole, the deposition hole is lined with highly compacted bentonite blocks to fill the empty space between the disposal canister and the bedrock. The disposal tunnels and the surface connections are backfilled and sealed.

The backfilling ensures the restoration of the natural state of the repository and the surrounding bedrock and prevents the excavated rooms from becoming conductors for groundwater. The backfilling also prevents unauthorized access to the repository.

For as long as the copper canister remains intact the interaction of the spent fuel with its surroundings takes place only in the form of thermal flows and by small amounts of gamma- and neutron radiation that penetrate the canister's wall.

2.1.2 Olkiluoto Baseline and Monitoring of Changes

The baseline conditions at Olkiluoto have been comprehensively studied and investigated prior to construction to distinguish how the excavation of the ONKALO and the repository will affect the bedrock and the groundwater conditions. At later stages and partially already now the selected follow-up points are monitored and the values are compared with the reference values from the baseline studies.

2.1.3 KBS-3 Concept

This facility description presents the disposal concept or the basic concept that is based on the long-term isolation with multiple engineered barriers complementing each other, where the engineered barrier closest to the spent fuel, i.e. the canister, is emplaced in the deposition hole drilled to the solid bedrock.

According to the disposal concept, the spent fuel assemblies are installed and enclosed within the cast iron insert which is surrounded by a copper canister. The copper canister lid and the shell are sealed tightly, so that the groundwater flowing in the bedrock does not come into contact with the cast iron insert or the spent fuel. This ensures isolation of the spent fuel and prevents release of radionuclide to the groundwater and thereby to the geosphere and to the biosphere. The single copper canisters are emplaced in the deposition holes at the bottom of the excavated disposal tunnels in the solid bedrock at a depth of 400-500 meters. Each vertical deposition hole is lined with bentonite, i.e. swelling natural clay material that serves as a buffer material between the host rock and the canister. Once the canister has been emplaced in a deposition hole lined with bentonite, an additional bentonite buffer is placed on top of the canister in order to fill the hole up to the level of the disposal tunnel floor. The purpose of the bentonite, after being saturated, is to severely limit the flow of groundwater around the canister, to conduct the heat produced by the spent fuel from the canister to the rock, to provide sufficient permeability to gases that are mainly formed inside the canister as a result of corrosion and, simultaneously, to absorb radio-nuclides, which could be released from the canister. The bentonite also provides mechanical support to the canister so that it remains in its original position. Bentonite, which is more elastic than the canister and the bedrock, protects the canister against minor rock movements. The near-field bedrock surrounding the deposition hole protects the canister against unfavourable disposal conditions and, as the last release barrier; the rest of the surrounding bedrock retards and dilutes any release of radio-nuclides from the canister.

The disposal tunnels will be filled with a mixture of crushed rock and bentonite, which will ensure that the bentonite buffer, while swelling, stays in the deposition hole and will prevent the disposal tunnels from becoming preferential conductors for groundwater. The backfill will also prevent unintentional and undeclared intrusion into the repository. The following describes the technical design, subsystems, operational requirements and operation principals related to the different release barriers.

2.1.3.1 Canister

The purpose of the canister, as an airtight and watertight unit, is to insulate the spent fuel. After several decades in interim store the spent fuel assemblies are loaded into a cast iron insert, which is surrounded by a copper overpack. The empty space inside the canister is filled with an inert gas in order to decelerate and minimize the internal corrosion caused by moisture and radiation.

The canister has to meet the following requirements:

- the corrosion lifetime in the bedrock conditions must be at least 100 000 years
- the canister must be mechanically robust, i.e. it must tolerate handling operations, deformations, internal pressure, hydrostatic pressure, swelling pressure of the surrounding buffer, minor rock movements and the load caused by future glaciations
- the sealing method must not reduce the required long-term performance of the canister
- the canister must have sufficient radiation shielding and thermal conductivity properties
- the cast iron insert must provide a significant chemical buffering capacity.

Furthermore, the spent fuel isolated in the canister must be sub-critical and remain sub-critical in the repository. Manufactured prototype canister can be seen in Fig. 1 below.

Fig. 1 Canister insert for BWR-fuel made of nodular cast iron on the left (Metso Foundries) and a copper overpack on the right (Vallourec & Mannesmann Tubes).

2.1.3.2 Buffer Material and Backfill Materials

Buffer material is used in the deposition hole where its function between the canister and the rock is

- to isolate the copper canister from the near-field bedrock and the processes in it
- to support the canister in its installation position
- to absorb minor near-field rock movements
- to prevent groundwater flows in the gap between the canister and the bedrock in such a way that mass transport (most significantly radionuclide transport) between the bedrock and the canister occurs mainly by diffusion.

The buffer material is bentonite, which is installed into the deposition hole around the canister. Bentonite is clay which, after saturation, swells and becomes plastic.

The buffer material has the following requirements. The long-term behaviour of the material has to be predictable, the material has to be chemically and mechanically stable, and the buffer material has to have:

- adequate swelling pressure (1-10 MPa)
- low hydraulic conductivity
- sufficient thermal conductivity
- sufficient bearing capacity
- sufficient plasticity and softness to dampen rock movements

- sufficient permeability to gases (produced mainly by corrosion of metals)
- ability to filter colloids
- ability to filter and limit growth of micro-organisms
- sufficient chemical buffering capacity
- ability to limit transport of corrodents and radio-nuclides, due to its good sorption properties and low diffusivity properties, which do not impair the capacity of other release barriers.

A disposal tunnel is backfilled after emplacement of all canisters and the installation of the buffer material, and this backfilling is carried out in stages throughout operation of facility. Finally, the surface access routes, i.e. the access tunnel and the shafts, are backfilled as the disposal process is complete.

The tunnel backfill in this facility description consists of crushed rock and bentonite. A programme of research and method development continues on backfill materials.

The requirements for the backfill properties are:

- low hydraulic conductivity
- long-term chemical and mechanical stability
- no harmful effects on the other barriers
- sufficient density and low compressibility
- adequate swelling pressure (approximately 100 kPa)
- ability to retain radio-nuclides (good sorption capacity).

2.1.3.3 Bedrock in the Near Field and in the Disposal Area

The main functions of the bedrock as part of the multi-barrier principle are:

- to isolate the repository from the biological environment and to protect it against external impacts and processes taking place near the ground surface
- to provide favourable and predictable mechanical, chemical and hydro geological conditions for the long-term isolation of the canister and the buffer and backfill material
- to limit the amount of groundwater coming into contact with the buffer and the canister and
- to retard and retain potential releases from the repository.

The following requirements are necessary for the bedrock and the groundwater flowing within it:

- the groundwater salinity must not be too high
- the pH of the groundwater must be close to neutral and its sulphate and sulphide contents must be low
- there must be only a limited number of groundwater paths in the bedrock
- the bedrock must have a sufficient mechanical strength and
- no fracture zones are allowed in the host rock in areas reserved for the disposal tunnels.

The host rock that is suitable for disposal is also well suited for the construction of underground spaces. The repository design aims to avoid fracture zones in the bedrock and mechanically or chemically unstable areas, as well as major water flow paths.

2.2 Design Basis

2.2.1 Legislative Requirements

The Government Decision dating from 1999 for the safety of spent fuel disposal is of particular importance to the disposal facility. In this decision, the dose limits for the disposal facility are stricter than those given to nuclear power plants.

2.2.1.1 Radiation Protection Requirements for Design

Radiation and Nuclear Safety Authority (STUK) specifies in Guide 8.4 the regulations given in Government Decision (1999) and points out that the disposal shall not under any assessment period have such an impact on health or the environment that would exceed the maximum level regarded as acceptable during the disposal implementation.

2.2.2 General Design Basis

The purpose of the spent fuel disposal facility is that the nuclear fuel assemblies generated in Finnish nuclear power plants are encapsulated in a form necessary for permanent disposal and are permanently disposed of in Finnish bedrock.

The disposal facility consists of two parts:

- facilities above ground, of which the most important building is the encapsulation plant. In the encapsulation plant, the spent fuel from Loviisa and Olkiluoto nuclear power plants, after having cooled in interim store facilities over several decades, is received, dried and packaged into disposal canisters
- repository, which consists of tunnels and deposition holes in the deep bedrock, where the spent fuel, packaged into canisters, is emplaced. Also necessary underground auxiliary rooms and access routes are included.

The total land area of the facility above ground, i.e. the area for buildings, roads, stores and fields, is approximately 15 hectares. There is one access tunnel leading from the surface to the repository plus the required number of vertical shafts for ventilation, personnel and canister transfer.

2.2.2.1 Canister Dimensioning Basis

The measurements of each fuel type, especially the length, determine the dimensions of the canister. The canister's outer diameter is approximately 1.050 m for all fuel types, but its total length varies depending on the fuel type. The canister length for current fuel types varies between 3.6 to 4.8 m.

The selection of fuel assemblies to be encapsulated has to be optimized with the help of annual fuel accumulation, burn-ups and plant operation time according to the following rules:

- cooling time for a fuel assembly has to be at least 20 years in order to achieve a sufficiently low radiation level
- thermal power rates per canister have to be limited to specified values
- disposal is to be carried out as quickly as possible, but at a steady rate
- overall cooling time of the fuel assemblies is determined by the thermal power allowed for a canister.

In the reference case, the calculated thermal powers for canister containing 12 assemblies can be, at the encapsulation phase, 1370 W maximum for the shorter Loviisa fuel and 1700 W for the Olkiluoto fuel.

2.2.2.2 Disposal Facility Operating Time

The operating time and capacity of the disposal facility are determined by two time limitations. The first time limitation is that disposal can start around the year 2020. The other time limitation is that all spent fuel, after removal from the reactor, has to cool much enough. A very essential process regulation for disposal is that the surface temperature of the canisters cannot exceed the allowed temperature of +100 ^{o}C during disposal.

2.3 Licensing and Permits

2.3.1 Decision in Principle

The Government approved the decision in principle (DiP) on Posiva's application concerning a disposal facility in 2000. According to this decision, it is in the general interest of society for a disposal facility to be developed at Olkiluoto in the municipality of Eurajoki. The government stated that the conditions of the DiP had been satisfied, because the municipality of Eurajoki accepted in 2000 that the disposal facility could be built at Olkiluoto. STUK also supported the project in its preliminary safety assessment. Following parliamentary approval of the DiP in 2001, Posiva has been able to focus on the research at Olkiluoto.

2.3.2 Construction Licence and Operating Licence

The DiPs from the Government are an important phase in the multiphase licence procedure, which, under the Nuclear Energy Act, are required for a disposal facility. Applications for a construction licence and operating licence for the disposal facility have also to be submitted to the Government.

An application for a construction licence needs to be submitted to the supervising authorities according to the current timetable and to the decision by Ministry of Trade and Industry (KTM) by the end of 2012. According to the DiP, the construction licence for the disposal facility has to be submitted at the latest by the end of 2016.

In its application for a construction licence for the disposal facility, Posiva has to submit to the authorities different kinds of reports to comply with the Nuclear Energy Act and Decree which describe safety in the facility, such as detailed technical plans, safety reports, and up-to-date environmental impact assessments for all the types of waste that is intended to be disposed of in the facility.

Reports for the design basis, which will be followed by Posiva in order to avoid environmental damages and to limit environmental stress, are also to be produced.

Before commissioning the disposal facility, under the Nuclear Energy Act, a separate application must be made to the Government for an operating licence, so that disposal can start around the year 2020.

2.3.3 Environmental Impact Assessment (EIA) as a Part of the Licensing

The material for the EIA for the facility was collected over the period 1997-99 and, as provided by the Act on Environment Impact Assessment Procedure, an EIA was prepared together with the DiP application in 1999. According to the results of the EIA, the environmental impacts of the project are generally insignificant.

2.4 Timetable for Disposal Operations

Currently in the facility design, the expected operating lifetime for the Loviisa plants is 50 and for the Olkiluoto plants 60 years. Therefore Loviisa units would cease operation around 2030 and Olkiluoto units around 2040. Currently, a third unit (Olkiluoto 3) is under construction in Olkiluoto and the spent fuel from it is also planned to be disposed accordingly in the same repository.

The preliminary timetable is based on the above-mentioned calculations. This means that the spent fuel from each plant unit has to be disposed of at the same rate as it is being generated. Therefore, Loviisa 1-2 units' spent fuel has to be disposed of from 2020 for 37 years, and Olkiluoto 1-2 units' spent fuel has to be disposed of from 2020 for 60 years.

3. GENERAL DESCRIPTION OF THE DISPOSAL FACILITY

The disposal facility consists of surface structures, buildings and related components, an underground repository and its access and maintenance routes. Besides traffic arrangements (roads and parking areas), the surface structures, buildings and related components include:

- encapsulation plant and operating building
- ventilation shaft building
- research building (incl. warehouse)
- building for tunnel technique (for the repository)
- repair shop
- information building
- crushed rock storage area and crusher station
- bentonite container storage area
- backfill material mixing station
- fuelling station and storage tank.

The underground repository consists of the following components and rooms:

- canister shaft and personnel shaft with lifts
- ventilation shaft with a lift
- access tunnel
- repair shop and washing and refuelling hall for vehicles
- central tunnels
- characterisation tunnels and levels
- disposal tunnels and deposition holes
- parking hall
- operation and decommissioning waste hall
- testing and demonstration rooms
- rescue chamber/office, brake and personnel rooms
- technical rooms, such as pumping station and sedimentation pools, fire-fighting water pools, electrical rooms and technical rooms.

Furthermore, the tunnel technique building above ground directly serves the repository, and can therefore be seen as part of the repository.

The most significant stages in the operation of the disposal facility are waste transport, encapsulation, canister transfer and canister emplacement in the deposition holes. Several preliminary stages are needed to support these operations, as described below.

Spent fuel generated in the nuclear power plants and cooled in the interim stores is transported from the Loviisa and Olkiluoto interim stores in transport casks to the encapsulation plant.

In the encapsulation plant, the transport cask is opened, spent fuel assemblies are lifted from the casks to be dried in the autoclave and placed into the canisters. The canister lid is sealed by welding, the weld surface is machined and the weld quality inspected. The canister that has passed inspection is transferred into the encapsulation plant's buffer store.

Canisters which are ready for disposal are transferred from the buffer store down to the repository using a canister lift. An optional way to transfer the canister down to the repository is to use a transfer vehicle and the access ramp. In the repository, the canister is moved from the lift to the canister transfer and emplacement vehicle and transferred to the deposition hole in the disposal tunnel in order to be emplaced. The same vehicle is used for both emplacement and transfer of the canister. Before the canister is emplaced in the deposition hole, the vertical hole is lined with bentonite discs and rings. When the canister has been lowered into the hole, bentonite blocks are placed on top of the canister using a special vehicle.

Disposal tunnels are backfilled gradually as canisters are disposed of in them. Before filling, ventilation, electricity and water systems are removed from the disposal tunnel, and the tunnel is cleaned. Backfill material is transferred into the repository using specially designed equipment and is spread and compacted in layers with a special backfill handling and compacting vehicle. The backfilled disposal tunnel opening is then sealed with a concrete seal, which keeps the backfill material in its position until the central tunnel is backfilled, thus preventing access to the disposal tunnel. During the operational stage, new disposal tunnels are excavated gradually as they are needed. Following its excavation, each disposal tunnel is supported and grouted as required before its characterisation in detail so that the positions of the deposition holes can be determined. Canister deposition holes are bored with full profile boring in the disposal tunnel floor.

4. STRUCTURE OF THE DISPOSAL FACILITY

4.1 Surface Structures and Buildings

The disposal facility at Olkiluoto comprises an independent operating system located above the repository. At the early stage of plant operation, the disposal facility and facility area utilize the existing infrastructure of the Olkiluoto nuclear power plant.

4.1.1 Area Plan

The encapsulation plant, operating building and information building are located around the canister shaft, west of the fresh-water reservoir. The ventilation shaft building and research building are placed around the ventilation shaft. The building for tunnel technique and the repair shop are located close to the access tunnel opening at the facility area.

Buildings in the area are separated from each other according to whether they are classified as a controlled area or an uncontrolled area. The access tunnel and the ventilation shaft are not part of a controlled area, i.e. there is no spent fuel handling in any form there. The main gate to the disposal facility is associated with the disposal facility operation building.

4.1.2 Encapsulation Plant

The encapsulation plant is the most important building of the disposal facility. The interim store for bentonite blocks will be built in conjunction with this plant.

According to the preliminary plans, the encapsulation plant is 65 meters long and 36 meters wide. The building is approximately 15 meters high and the building volume is approximately 40 000 m^3. The building will have six storeys.

Heavy traffic will be limited to the ground level of the plant through doors opening directly out. Fuel transport casks are delivered to the reception area by a road transport trailer. The reception area is a drive-thru area. New disposal canisters are transferred to the plant by lorry.

The average encapsulation rate at the encapsulation plant is 40 canisters per year, with the maximum rate being 100 canisters per year. The encapsulation plant is designed in such a way that all the spent fuel that is generated in Finland can be encapsulated there.

The encapsulation plant is designed in compliance with all current safety regulations so that in the event of disturbance or accident, the release of radioactive materials into the environment remains insignificant. All operations in the encapsulation plant are to be carried out safely and without any significant releases and personal doses.

The main sections of the encapsulation plant are:

- spent fuel reception
- hot cell (encapsulation)
- welding chamber (lid sealing)
- weld inspection
- canister transfer corridor
- control room
- canister lift (missing, if ramp transfer is used)
- plant systems (for encapsulation, control, communications, HEPAC, etc.)
- bentonite block interim store.

The most demanding operations are carried out in the hot cell and in the welding chamber at ground level. The hot cell is equipped with an autoclave, a crane, a fuel transfer device and manipulators. Behind the radiation shield windows of the hot cell is the operation control room. Spent fuel assemblies are removed from the transfer casks and are placed in the autoclave to be dried and finally transferred into disposal canisters using a crane-type fuel transfer device in the hot cell.

The hot cell is completely lined with stainless steel and has exhaust ventilation and filtration systems. The hot cell has a vacuum-cleaning system, which gathers all active crud or small loose particles, which may have fallen from the fuel assemblies, and places them into the disposal canisters. The welding chamber is located above the canister transfer corridor. The welding chamber is equipped with an electronic beam welding device and a docking station, to which the canister top is docked for welding.

The repair shop for hot cell devices is located above the hot cell. The repair shop also serves as a decontamination room. The service crane installed in the repair shop serving the hot cell is used for lifting the hot cell devices to the repair shop through the hot cell roof hatch, and further, if needed, to the work shop at ground level. Rooms for electrical equipment, auxiliary rooms and storages are also located at ground level. The interim store for bentonite blocks is located at the end of the encapsulation plant. Images from 3D plan of the encapsulation plant are seen in Fig. 2 below.

Fig.2 Section of encapsulation plant on the left and a view of the encapsulation plant and the operational office building plans above ground at repository site.

4.2 Repository

The planned total excavated volume of the repository is approximately 1 310 000 m^3. The volume of momentarily open excavations at any time is a maximum of approximately 620 000 m^3 (47 % from the total volume). Most of the open excavations lie within the uncontrolled area. The volume of the controlled area during repository operation varies from 10 % to 30 % of the volume of open excavations at any one time. The maximum volume of the controlled area is 150 000 m^3, and the maximum volume of the uncontrolled area 540 000 m^3.

Thermal analysis provides a starting point for repository design and has an important influence on the effectiveness of the disposal operation. These on the other hand affect the volume of rock reserve needed for excavating tunnels and the disposal facility lifespan.

In the one-storey layout option, all spent fuel is disposed of on one level. The repository length in a north-south direction is around 1.3 km and its width in an east-west direction around 2.3 km.

4.2.1 Access Routes

According to the current repository design, one access tunnel and three shafts (canister shaft, personnel shaft and ventilation shaft) are constructed. The access tunnel and the ventilation shaft are built in association with the construction of the ONKALO.

The access tunnel descends clockwise, making it possible for vehicles driving upwards to use the less steep outer curve of the tunnel. The access tunnel floor is made of concrete. Characterisation niches will be constructed at different depths in the access tunnel to investigate the bedrock. The access tunnel's length will be about 5500 m with an inclination of 1:10, the excavation height will be 6.3 m (free height of 4.5 m), and the width 5.5 m. The tunnel is wider and has an increased gradient in passing lanes and around curves

The excavation, design and characterisation of the access tunnel will be carried out in compliance with the CEIC-principle (Coordination of Engineering design, Investigations and Construction). CEIC is a co-ordination process, which utilises, in design and construction, the characterisation data collected from the construction of the ONKALO.

The main purpose of CEIC is

- to ensure that the repository layout is adapted in an optimal manner to local conditions
- to adjust the excavation methodology to actual rock conditions
- to speed up the decision making process by determining the criteria for decisions in advance
- to ensure proper documentation and enable traceability between requirements, decisions and implementation.

Additionally two shafts will be built to the controlled area: a canister shaft and a personnel shaft. The upper part of the canister shaft is connected to the encapsulation plant. Canisters ready for disposal are transferred from the buffer store down to the repository level by the canister lift; the same applies for bentonite blocks and operating waste and decommissioning waste. An optional way to transfer the canister and the bentonite blocks down to the repository is to use a transfer vehicle and the access ramp. The canister lift is not used for personnel or for transporting visitors. Ventilation ducts and electric cabling are also located in the canister shaft.

The personnel and canister shafts are circular in cross-section and are lined with 300 mm of concrete from the ground level to level 100 m. The lower parts of the shafts are reinforced with shotcrete. The personnel shaft's inner diameter is 3.0 m and the canister shaft's inner diameter 6.5 m.

The upper part of the personnel shaft is connected to the operation building. The personnel shaft's lift takes personnel to the controlled area of the repository. The uncontrolled area is entered via the access tunnel and the ventilation shaft and both personnel and visitors going to the controlled area use the personnel shaft. The personnel shaft lift is powered by a drum hoist engine modified from a mine lift.

4.2.2 Central and Disposal Tunnels and Other Rooms for Disposal Operations

The repository comprises central tunnels, disposal tunnels and auxiliary rooms relating directly to the disposal operations and is divided into controlled and uncontrolled areas. The controlled area, which is part of the nuclear plant, comprises technical rooms, the canister shaft, the personnel shaft, part of the central tunnels and the disposal tunnels where spent fuel is disposed of in each operational stage.

The design of the ONKALO allows it to become an integral part of the repository. The design basis for the ONKALO is to alter the disposal site environmental conditions as little as possible, and not to jeopardise the use of favourable bedrock for disposal.

4.2.2.1 Parallel Central Tunnels

The central tunnels and disposal tunnels can be situated according to the principle of a parallel central tunnel. The parallel central tunnel layout is based on the idea that one tunnel is connected to the controlled area of the central tunnel, and the other tunnel to the uncontrolled area (of the central tunnel). A fixed boundary of the controlled area is located in the central tunnel between the parallel tunnels and the zone boundary of flexible controlled area is shifted along the parallel tunnel towards the uncontrolled area as disposal proceeds. Connecting tunnels will be constructed between the parallel tunnels.

The parallel tunnel layout provides better emergency exits and fire safety (fire compartments). The tunnels are separated from each other, and separate fire compartments and connecting tunnels will be excavated between them every 100 metres. In the event of a fire or tunnel collapse, there will always be another escape route providing an emergency exit from the parallel tunnel. In the event of an accident, moving from one tunnel to another via the connecting tunnel provides fast moving from one fire compartment to another. Implementation of the ventilation main ducts and power supply main busbars in the parallel tunnel principle is also a practical proposition.

4.2.2.2 Disposal Tunnels and Deposition Holes

The total volume of the repository consists mainly of disposal tunnels, which are only excavated as required. The lifespan is short; the tunnels are excavated in stages during the disposal operation and backfilled as quickly as possible after the canisters have been emplaced. It is sensible if the disposal tunnels are made as small as possible within the constraints imposed by canister emplacement and safe operational practice. This will ensure that disturbance to the bedrock and the groundwater system is minimised and will enhance the long-term safety of the repository.

Disposal canisters are emplaced into the deposition holes bored in the floor of disposal tunnels. The deposition hole diameter is 1750 mm and the hole has a depth of 6.6 m or 7.8 m for various types of canisters. The distance between deposition holes is from 8.6 m to 11.0 m for various canisters. The allowable minimum distance between disposed canisters is strongly dependent of initial canister heat output and the local bedrock thermal properties.

4.2.3 Repository Layout Adaptation

The spent fuel repository layout design is based on avoiding hydraulically conductive cracks or zones and fracture zones in the bedrock as much as possible, as well as on the bedrock having sufficient thermal conductivity in order to keep the canister temperature within the allowable limits. The decay heat power impact can be controlled by means of layout adaptation by locating the canisters and the disposal tunnels at a greater distance from each other and by taking care of the thermal conductivity of the canisters in the near-field host rock and the surrounding bentonite buffer.

5. DISPOSAL FACILITY OPERATIONS

The disposal facility starts to operate in 2020 after the operating license under the Nuclear Energy Act has been obtained. The operation includes among other things encapsulation, canister emplacement, tunnel backfilling, construction during operation (repository enlargement), transfer and control.

5.1 Construction in Phases

The actual implementation of the facility is carried out in phases. By the year 2020, only a small part of the disposal tunnels will have been constructed. Initially, disposal tunnels covering a few years' disposal needs will be constructed at level - 420 m. The need for heating, ventilation and seepage drainage is also lower, as the volume of excavated underground room open at the same time remains small. Constructing in phases also avoids need for construction overcapacity.

More rooms are excavated as the disposal progresses. Both disposal and excavation are thus being carried out at the same time, but in separate tunnels. The chosen implementation strategy determines the excavation and construction volume to be undertaken in an enlargement stage at a time. The disposal operation thus proceeds in this manner by enlarging the repository in stages from 2020 until 2126, when disposal is suggested to end. Progress in stages always includes layout design, characterisation and construction of the central tunnel, disposal tunnels and deposition holes for each stage.

5.2 Facility Personnel

Some 120 persons with various tasks relating to facility operation, maintenance, control and administration will be working in the disposal facility. There are several different tasks and operations: spent fuel reception and encapsulation, disposal operation, control room operations, cleaning and maintenance of premises and equipment, as well as administration and finance, radiation control, security operations and operations in the visitor centre.

5.3 Spent Fuel Transport and Transfers to the Encapsulation Plant

Currently the spent fuel is stored in the interim stores in the Loviisa power plant at Hästholmen and in the TVO power plant at Olkiluoto. From these interim stores the spent fuel will be transported to the encapsulation plant in special transport casks as special transports.

5.4 Encapsulation Plant Operations

Fuel assemblies are transferred in transport casks from the spent fuel interim store and sealed in copper canisters in the encapsulation plant. In the hot cell, fuel assemblies are placed into the fuel channels inside the canister's insert. The canister lid is sealed by welding and the seam is inspected by an ultrasonic inspection device and with an X-ray system. If the inspection result meets the requirements, the canister is then ready for disposal and transferred to the buffer storage for transfer down to the repository. Otherwise the canister is sent back, either to be repaired or dismantled.

5.4.1 Receiving Spent Fuel

The fuel assemblies are transferred (in transport casks) from the interim store to the encapsulation plant by a special transport vehicle. After cleaning, the transport vehicle is driven into the cask receiving area of the encapsulation plant. The weather guard is opened and the collision shock absorbers of the cask are removed. The cask is lifted, either to be stored in the receiving area or to be taken down to the cask transfer corridor.

The disposal canisters are prepared, inspected and assembled in the machine workshop and transferred to the encapsulation plant by lorry. During transfer, the canister is protected by a transport frame, which is used for further canister handling. The transport frame is lifted to the new disposal canisters' store in the encapsulation plant and stored in vertical position. The store for new canisters has space for 24 canisters.

5.4.2 Encapsulation and Hot Cell Operations

The copper canister is lowered from the transfer frame into the canister transfer trolley which moved under the hot cell docking station. The canister is lifted and docked tightly to the lower structure of the docking station's covering hatch with a double gasket.

After docking to the hot cell, the cask lid is opened by remote control. The fuel assemblies are lifted out of the cask one at a time. The identification of each assembly is checked. According to the encapsulation strategy, each canister will contain spent fuel of various ages (i.e. older and younger fuel) in order to keep the decay heat in canisters as similar as possible and in accordance with the calculations. The fuel transfers are planned in such a way that thermal optimisation can be carried out during the encapsulation process.

The spent fuel assemblies are placed into an autoclave to be dried. After drying the fuel assemblies with flow channels are transferred one at a time from the autoclave into the canister in the encapsulation chamber by remote control. A maximum of 12 fuel assemblies are placed into one canister. The encapsulation process is monitored from the control room located behind the hot cell. The control room has a view to the hot cell through radiation shielded windows.

5.4.3 Closing of the Canister Lid

After the fuel assemblies have been placed into the canister, the sealing surfaces of the canister are inspected. The copper surface (to be welded) is also checked for purity and soundness. After this, a gas atmosphere changing cup is lowered on top of the canister and tightened by expanding gaskets. A vacuum system removes air from the cup and the canister is filled with inert gas (e.g. argon or helium).

Next, the lid of the iron insert is lowered into place and adjusted to the insert's end by a 50 mm deep conic fitting, which is also provided with gaskets. The insert's lid is then closed with one bolt in the centre of the insert.

After verifying the inner lid's tightness, the gas changing cup is removed from the top of the canister and the docking station hatch is lowered back into place and tightened. The canister's seal to the hot cell is detached and the canister is taken down to the canister transfer trolley in the transfer corridor.

In the transfer corridor, the copper lid of the canister is placed on the canister. After this, the canister transfer trolley takes the canister under the welding chamber. The canister is lifted to the welding chamber so that the upper part of the canister is inside the chamber. The canister is then tightened to the welding chamber by gaskets.

Before the copper lid is welded a vacuum is formed in the welding chamber. The copper lid is sealed by electron beam welding. After welding the vacuum is released and the canister is lowered back to the transfer trolley.

5.4.4 Sealing Weld Inspection

The first weld inspection can be carried out during the welding process through the lead glass windows or by camera provided in the chamber.

The weld surface is machined with a milling machine in the transfer corridor by remote control. After machining, the milling chips are vacuumed from the canister's upper surface and the weld is inspected by volumetric ultrasonic testing.

After welding and inspection, the canister is taken to the cleaning station and any dust/dirt on the canister surface is washed off.

After cleaning, the canister transfer trolley takes the canister to the X-ray inspection station. During the volumetric X-ray inspection of the weld the canister rotates about its vertical axis. The X-ray gun is aimed at the back wall of the inspection cell. The X-ray inspection requires proper radiation shielding. If the weld fails to pass the inspections, the canister is returned for repair.

5.4.5 Storage and Handling of Finished Canisters

After weld inspection the canister transfer trolley takes the canisters to the buffer store to wait for transfer to the repository using an automatic guided vehicle. The buffer store can accommodate 12 canisters.

5.4.6 Interim Store and Transfer of Bentonite Blocks

Bentonite blocks to be installed in the deposition holes are transferred to the repository through the canister shaft. For this reason, the interim store for bentonite blocks is built in association with the encapsulation plant. Bentonite blocks are purchased ready from a third-party supplier on the basis of competitive bidding. The blocks are compacted from a refined bentonite powder at a pressure of ca. 100 MPa.

Bentonite blocks are transported to the interim store in metal containers. In the interim store, the bentonite blocks are unpacked from the containers and loaded onto a transfer frame to be transferred to the repository. Bentonite blocks are taken down by the canister shaft lift. The canister shaft lift is entered through an airlock from the bentonite block interim store. An optional way to transfer the canister down to the repository is to use a transfer vehicle and the access ramp.

The buffer of one disposal canister requires approximately 10 m^3 or 20 tonnes of compacted bentonite blocks per deposition hole.

5.5 Canister Transfers from the Encapsulation Plant to the Repository

The canister is transferred to the repository by the canister lift or in an optional using a transfer vehicle and the access ramp. The canister lift's load needs to be minimised (lift total load is ca. 30 tonnes). The canister lift cage is a one-store cage. In the encapsulation plant and in the repository, the lift has two station levels: the lower level is for disposal canisters and the upper level for bentonite blocks.

In the encapsulation plant, the canister is taken to the canister shaft lift by an automatic guided vehicle. At the repository level, the same vehicle takes the canister out of the lift to the canister loading station and further to the canister transfer and emplacement vehicle. The automatic guided vehicle is electric and has a carrying capacity of 25 000 kg. In the unlikely situation where a canister falls whilst being lifted into the radiation shielding of the canister transfer and emplacement vehicle, the automatic guided vehicle serves as a shock absorber for the canister.

5.6 Repository Operations

5.6.1 Excavation and Construction of the Repository

The construction of the repository comprises excavation work, construction engineering works and mechanical works. Excavation work includes (among other things) excavation, reinforcement and the boring of deposition holes. Construction engineering includes building floors in the disposal tunnels, walls in the shafts and building pumping station and sedimentation pools. Mechanical works include the implementation of various systems, such as ventilation and electrical systems.

5.6.1.1 Characterisation of Disposal Areas

Posiva's underground characterisation programme aims to ensure the suitability of the bedrock properties at the disposal site, to select the most favourable rock mass for disposal and to characterise the bedrock properties in general. The result of this characterisation programme will be used to design the facilities and to make construction plans, as well as to produce safety analysis. The characterisation programme is focused on bedrock structures and fracture zones and rock type properties, groundwater salinity, groundwater flow paths and factors having an impact on them, as well as on mechanical and thermal properties of the bedrock before the construction of the repository and during its enlargement.

5.6.1.2 Preventing Water Inflow into the Repository

The tunnels can be sealed by grouting in order to limit the groundwater inflow into the repository and the disturbance due to it. Groundwater flowing into the underground spaces and pumping the water to the surface during construction and operation of the repository cause groundwater fluxes in the bedrock, the migration and mixings of different types of water and drawdown of the groundwater table. The water inflows also result in the migration of superficial waters into the deep bedrock. The most significant impacts in relation to post-closure conditions are those relating to groundwater inflows into the deep parts of the repository during its operation.

5.6.1.3 Handling of Excavated Rock

The excavated rock is transferred to the surface via the access tunnel by trucks and unloaded in the blasted rock yard. When needed, the blasted rock is transferred from the blasted rock yard to the crushing plant. Crushed rock will be stored in the crushed rock storage area. In the operational stage, crushing is planned to be carried out every other year as separate projects lasting for approx. two months.

5.6.1.4 Boring of Deposition Holes

The deposition holes are bored through the disposal tunnel floor by full profile boring. Crushed rock generated by boring is vacuumed into tanks and transferred to the surface via the access tunnel. The deposition hole is covered by a steel cover plate after the boring.

Where the deposition hole is considered to be unsuitable for disposal, for example due to excessive water inflow or fracturing, it will be discarded and filled with crushed rock and bentonite.

5.6.2 Canister Emplacement

Emplacement of canisters starts in the tunnels nearest to the canister shaft. The deposition hole is lined with bentonite (bottom and sides) before the canister is emplaced.

The bentonite blocks are transferred in transfer frames from the encapsulation plant buffer store to the repository by the canister lift or via the access ramp. The bentonite blocks are moved from the canister lift lower station and taken to the deposition holes in the disposal tunnel and installed in the deposition hole by the transfer and installation vehicle for bentonite blocks. Canister installation vehicle and principle of buffers and backfilling is shown in Fig. 3.

5.6.3 Backfilling of Disposal Tunnels

The disposal tunnels are backfilled as canisters are emplaced in them. The canister disposal and the backfilling of tunnels can be processed in cycles. The cycle length depends on the desired disposal efficiency, but it cannot be much longer than one month. The disposal canisters should not be kept for weeks in open deposition holes, because the water inflow into the holes cannot be completely prevented before the tunnel above the hole is backfilled.

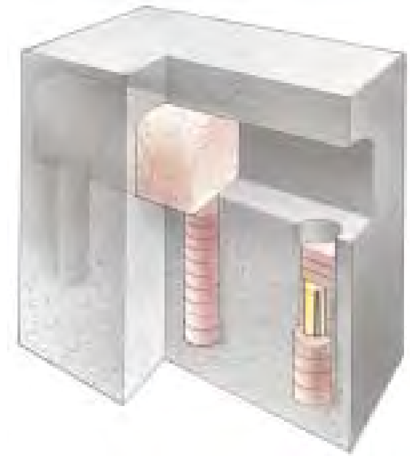

Fig.3 The canister transfer and installation vehicle on the left (Posiva) and the principle of bentonite buffer and tunnel backfilling in the repository (SKB picture).

5.7 Determination of Operational Safety

Under government decision 1999, the disposal facility and its operation are to be planned in such a way that, as a consequence of normal operation of the facility, discharges of radioactive substances to the environment should remain insignificantly low. Radioactive releases to the environment as a consequence of undisturbed operation of the facility are regarded as insignificantly low, when the average annual effective dose to the most exposed members of the public is maximum 0.01 mSv.

The disposal facility operations, building structures and systems are to be planned in such a way that radioactive releases into the rooms in the facility and into the environment are prevented or restricted by all practical means possible. The facility has to be provided with the technology for capturing radioactive substances released in the handling rooms and for decontaminating surfaces as well as for appropriate handling and packaging of the accumulated radioactive wastes.

5.7.1 Radiation Safety

5.7.1.1 Normal Operation

Assuming undisturbed operation of the encapsulation plant, the releases to the environment, and thus the radiation exposure of the public, would remain significantly low according to calculations. In normal operation, the handling of spent fuel transfer casks, for example, exposes the operating personnel to insignificantly low doses, as verified in the measurement of such transfers carried out at the Olkiluoto plant.

In normal plant operation, the maintenance and cleaning of the hot cell equipment causes small radiation doses to the personnel. The maximum radiation dose to the most exposed person is estimated to be 0.01 mSv per year.

5.7.1.2 Incidents

An anticipated operational incident refers to an incident, which has an impact on safety, and which is estimated to occur on average less frequently than once a year, but which has a significant probability of occurring at least once during the plant's operational life. As a result of an operational incident, spent fuel might be damaged, the radiation dose rate might increase, the activity concentration of radioactive substances in the disposal facility might increase or radioactive substances might be released to the environment.

5.7.1.3 Accidents

A postulated accident refers to an accident used as a design basis for safety operations in the disposal facility, which has only a small probability of occurring during the plant's operation. As a result of a postulated accident, fuel pins could become loose, large doses of radioactive substances might be released to the facility rooms or significant amounts of radioactive substances might be discharged into the environment.

Postulated accidents has been examined, as a spent fuel transfer cask falling, a transfer cask lid falling in the hot cell, a spent fuel assembly falling in the hot cell, a disposal canister falling, a canister lift falling in the shaft, a disposal canister falling into the deposition hole, a small aeroplane crashing, an earthquake, pipes and tanks breaking, a loss of heat transfer and overheating of the fuel, an explosion in the repository, a disposal tunnel collapse or a criticality accident.

According to the calculations the radiation doses in operational incidents and postulated accidents also remain below limit values given by the authorities.

6. REPOSITORY CLOSURE AND RETRIEVABILITY

6.1 Closure in Phases

The lifespan of the nuclear power plants of the different operators vary. In the disposal facility design, provisions are made for spent fuel from the different operators to be disposed of in such a way that the locations and numbers of the emplaced disposal canisters can be verified. Furthermore, all disposal canisters are to be emplaced in sealed disposal tunnels and the central tunnel or disposal panel tunnel connected to them must also be sealed. Spent fuel from a single power plant or power plant unit will thus be disposed of behind two backfilled and sealed tunnels in the repository.

The closing of disposal panels is carried out by dismantling the built structures in the associated disposal tunnels and central tunnels, by backfilling the excavated rooms and by constructing the sealing plugs for the disposal tunnels.

6.2 Decommissioning

Decommissioning refers to the operations that are carried out after the operation of a nuclear facility has ceased. The nuclear facility is made environmentally safe by dismantling it and taking care of any waste that has been produced. The closure of the repository is carried out partly during the operational stage and partly during the decommissioning stage.

6.3 Retrieve of Canisters during Operation and after Closure

The retrievability of the canisters from the repository has to be ensured after closure and during the period of time where the engineered barriers are assumed to almost completely prevent radioactive substances from being released into the bedrock. The disposal is to be designed in such a way that canister retrieval, if required, can be carried out in all operational stages with the technology available at that time and at reasonable costs. The design of the post-closure monitoring system must not, however, jeopardise the long-term safety of the repository.

7. SUMMARY

Spent fuel generated in Finnish nuclear power plants will be disposed of at Olkiluoto in Eurajoki. A disposal facility comprising an encapsulation plant on the surface, other buildings and structures on the surface and a repository in the deep bedrock will be built at Olkiluoto.

The repository planning has been divided into three-year periods and aims at being prepared for submitting an application for a construction licence to the authorities in 2012. This facility description is based on the preliminary design dating from 2003, which is the first Olkiluoto-specific disposal facility design. The next updated facility design and facility description will be presented in 2006.

Posiva's disposal plan is based on the KBS-3 concept, or vertical disposal concept. Long-term safety is based on the multi-barrier principle, which refers to several release barriers that support one another so that insufficiencies in the performance of one barrier do not jeopardize the long-term safety of the disposal system.

For underground investigation purposes, the construction of the underground rock characterisation facility, the ONKALO, will be started in 2004. The ONKALO will be designed in such a way that it can later be used as part of the repository. The underground research aims to ensure the suitability of the chosen site by identifying the favourable parts of the rock mass for disposal by characterising the rock conditions in detail.

The repository and its operation are designed in accordance with existing legislation and regulatory guides concerning the use of nuclear energy. An access tunnel and three shafts with lifts provide access routes to the surface. Apart from the underground rooms for disposal operation, such as disposal tunnels and deposition holes in the disposal panels, central tunnels and auxiliary and technical rooms in the controlled and uncontrolled area will be provided. The repository will be enlarged in stages as disposal progresses. The access tunnel is mainly used for the transfer of large material flows, such as blasted rock, backfill material and building materials. The repository and the encapsulation plant will be constructed in 2010s.

The aim is to start disposal facility operations in 2020. According to current knowledge, the disposal operations continue into the 2120s. At the start of operations, spent fuel from Loviisa and Olkiluoto power plants is transported in transport casks by road to the encapsulation plant. In the encapsulation plant, the transport casks are opened; the fuel assemblies are lifted out of the cask one at a time and placed in an autoclave for drying. After drying, the fuel assemblies are placed into disposal canisters.

The disposal canister comprises an inner nodular cast iron insert provided with a lid and an outer copper overpack, which is 5 cm thick and corrosion proof. The copper lid is sealed by welding. After weld machining and weld inspection, the canister that meets the criteria for disposal is transferred to the buffer storage in the encapsulation plant. From the buffer store, canisters are taken to the repository by the canister lift or via the access ramp. In the repository, the canister transfer and emplacement vehicle takes the canister from the lift to the deposition hole in the disposal tunnel. The same vehicle places the canister into the deposition hole bored in the rock. Before canister emplacement, the hole is lined with bentonite blocks and rings. After the canister has been emplaced, additional bentonite blocks are placed on top of the canister.

The disposal tunnels are backfilled as the canisters are emplaced. Before backfilling, the concrete floor and the ventilation, electrical and water systems are dismantled and the tunnel cleaned. The backfill material is spread and compacted into the tunnel. After the entire tunnel has been filled, a concrete plug will be built at the tunnel opening. During the operational stage, disposal tunnels are excavated as disposal progresses. Disposal is thus carried out in stages.

At the end of the disposal operation, the encapsulation plant is demolished and decommissioned appropriately. The repository and the access routes are backfilled and concrete structures will be built at tunnel openings; thus no subsequent monitoring has to be organised at the site in order to ensure long-term safety.

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