POSIVA’S DEEP GEOLOGICAL REPOSITORY FOR SPENT NUCLEAR FUEL

Lappeenranta–Lahti University of Technology LUT

Technology and Engineering science

2024

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Examiner: Giteshkumar Patel, D.Sc. (Tech.)

ABSTRACT

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Posiva's deep geological repository for spent nuclear fuel

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This bachelor's thesis handles spent nuclear fuel repository located in Olkiluoto Finland constructed by Posiva. Posiva has applied for an operation licence which the Finish nuclear safety authority is reviewing. Once the facility begins its operation, it will be the world's first deep geological repository for spent nuclear. This thesis gives background information on the handling of spent fuel and the construction of the final disposal site, before going deeper into the different release barriers used to prevent radioactive material from coming into contact with public, followed by overview of the different facilities at the disposal site and their function during the operational period. This thesis is done as a literature review using material provided mainly by Posiva. Material provided by Finnish authorities, International atomic energy agency and Finnish nuclear power plant operators is also used.

This thesis concludes that Posiva has considered safety of its employees during the operational period, and that the release barriers should be able to isolate radioactive material for 10 000 years. Furthermore, despite some operational licence application setbacks, the facility could begin operations during 2025.

TIIVISTELMÄ

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Posivan syvä geologinen varasto käytetylle ydinpolttoaineelle

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Tämä kandidaatintyö käsittelee Posivan rakentamaa käytetyn ydinpolttoaineen loppusijoitus laitosta Olkiluodossa. Posiva on hakenut laitokselleen käyttölupaa, jota Säteilyturvakeskus käsittelee. Toimiluvan saatuaan laitos on maailman ensimmäinen syvä geologinen varasto käytetylle ydinpolttoaineelle. Työssä annetaan taustatietoa käytetyn ydinpolttoaineen käsittelystä ja loppusijoituslaitoksen rakentamisesta, jonka jälkeen työ esittelee vapautumisen estot, joilla estetään radioaktiivisen aineen vapautuminen, jota seuraa katsaus loppusijoitusalueen eri laitoksiin ja niiden rooliin käyttövaiheessa. Tämä työ on tehty kirjallisuuskatsauksena käyttäen pääasiassa Posivan julkaisemaa materiaalia. Viranomaisten, kansainvälisen atomienergiajärjestön ja suomalaisten ydinvoimaloiden operaattoreiden tuottamaa materiaalia käytetään myös.

Työ toteaa Posivan ottaneen työntekijöidensä turvallisuuden huomioon käyttövaiheessa, ja vapautumisen estojen pystyvän eristämään radioaktiiviset aineet noin 10 000 vuodeksi. Lisäksi käyttölupahakemus prosessissa tapahtuneista vastoinkäymisistä huolimatta laitos voi olla käytössä jo vuonna 2025.

SYMBOLS AND ABBREVIATIONS

Roman characters

x	distance	m
m	mass	tU

Abbreviations

HLW	High Level Waste
DGR	Deep geological repository
STUK	SäteilyTUrvaKeskus (Finnish Nuclear Safety Authority)
TVO	Teollisuuden Voima Oyj
EPR	European Pressurized water Reactor
BWR	Boiling Water Reactor
VVER	Water-water energy reactor (Vodo-Vodjanoi Energtitšeski Reaktor)
OL	OLkiluoto

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1 Introduction

One of the major drawbacks of using nuclear technology for power generation is the radioactive waste it generates especially; high-level waste (HLW) imposes major risks for human health and the environment. The disposal of HLW is associated with some technical problems, but the development of disposal facilities has been mostly hampered by the general lack of support from the public due to safety concerns. However, the disposal of radioactive waste is not a problem that can be ignored and in recent years there have been significant progress made in the development of safe and efficient disposal methods of nuclear waste, including development of facilities for the disposal of HLW, so called deep geological repositories (DGR). According to IAEA there are GDR projects underway in Canada, France, Sweden and Switzerland, but none of these projects has gotten as far as the Finish Posiva DGR. (Watson, 2022) (Ojovan & Lee, 2014)

The Finish Posiva DGR will be the first disposal facility of its kind in the world. The disposal method is based on KBS-3 concept developed by Swedish nuclear fuel and waste management company SKB. The method is comprised of storing HLW into corrosion resistant canisters and storing them inside the repository walls in the depth of 450 meters. (Mikhailova, 2019)

This thesis aims to review currently available literature to form a picture how the Posiva’s disposal facility operates and fits into the Finish nuclear infrastructure. The thesis begins with overview of the handling of spent fuel in Finland and the background and current progress on the Posiva GDR. After this the thesis goes over the KBS-3 disposal concept, focusing on the different release barriers the disposal facility utilizes. This is followed by an overview on the disposal facility itself, presenting different parts of it and what role they play in the facility. Finally, the thesis summarises the findings and presents conclusions.

2 Finnish nuclear waste management

In Finland there are five operational nuclear reactors, two in Loviisa and three in Olkiluoto. The Loviisa power plant operated by Fortum has two Soviet made pressurized water reactors, often abbreviated as VVER. The Olkiluoto powerplant operated by Teollisuuden voima Oyj (TVO) has two boiling water reactors of Swedish design and the third and the newest reactor is an European pressurized water reactor (EPR). (STUK, 2024a) The nuclear waste generated in Finland comes primarily from these two plants (STUK, 2024b).

2.1 Handling of spent fuel in Finland

Highest regulatory framework which regulates the handling of nuclear waste in Finland is the Nuclear energy act (STUK, 2024c). The act includes a chapter on nuclear waste management, which obliges companies using nuclear technology for energy production to handle their waste in an appropriate manner and to keep their waste generation to a minimum. The act also mandates clearance levels, which are safeguards to ensure that any exposure due to nuclear waste has no significant effect on the public, and prohibits reuse, recovery and recycling of spent fuel. (Nuclear energy act 990/1987) The regulations on the handling of nuclear waste are supplemented by the Radiation and nuclear safety authority’s (STUK) Regulation on the safety of disposal of nuclear waste, which give regulations on the handling, storage and disposal of spent fuel and other nuclear waste within nuclear powerplant and in facilities constructed into the bedrock or into the ground. (Regulation on the safety of disposal of nuclear waste STUK Y/4/2018)

In Finland spent nuclear fuel is always classified as high-level waste (HLW) (STUK, 2024b). After the fuel is removed from the reactor, it is highly radioactive and generates significant heat. Initially it is stored in water pools within the reactor building to ensure proper cooling. The water used in storage also acts as radiation shielding. The spent fuel will be stored in the reactor building for around five years, (TVO, 2024a) after which it can be transported into intermediary storage facility placed within the powerplant area where it will be stored again in water pools to cool the fuel further. The spent fuel can be stored in the intermediary storage for decades. (TVO, 2024b) After the intermediary storage the fuel will be stored in the Posiva final disposal facility once it begins operations (TVO, 2024c).

2.2 Background and current progress on Posiva DGR

In 1994 an amendment was added to the nuclear energy act which mandated that all nuclear waste generated in Finland must be handled and disposed in Finnish territory, while also banning the import of nuclear waste generated abroad (Nuclear energy act 990/1987, amendment 1420/1994). Posiva was founded in 1995 by TVO and Posiva, as a result of this amendment to develop a solution for handling and disposing spent fuel. Later in 2000, it was decided by the Finnish government that a DGR would be the safest and most feasible method of final disposal. (Posiva, 2024a) (Posiva, 2024b) (Potterton, 2011)

Immediately after Posiva was founded, search for a location was started. These investigations focused on the bedrock and the suitability of the infrastructure in the areas. The final decision was ultimately made between Loviisa and Olkiluoto, the towns where the two nuclear power plants in Finland are located, as the inhabitants in these towns were already accustomed to nuclear powerplants operating in vicinity. Finally, the island Olkiluoto was chosen as the location for the disposal site. The 2000 decision by the Finish government which mandated GDR as the Finish solution for spent fuel disposal, also required more thorough geological research into the bedrock, which were concluded in 2004 when the final decision to begin construction was made. (Posiva, 2024b)

The construction permit given in 2004 gave permission to begin construction of research facility called ONKALO. The research facility would be comprised of the main research facility and lower research facility, and this construction phase would also include the construction of drive shaft connecting the main research facility to the surface as well as a ventilation shaft. Once the ONKALO facility is operational, the construction of disposal facility would begin. During this phase more tunnels would be drilled from the ONKALO. These tunnels would then be used to store the spent fuel. The drilling of these deposition tunnels would also continue into the operational phase of the facility. (Kirkkomäki, 2004)

Posiva applied for permission to begin the construction of the disposal facility in 28.12.2012 from the Finish government (Posiva, 2012). The application was approved in

2015, and the construction of the disposal facility began the same year (Posiva, 2024c). On December 30, 2021, Posiva applied for operation license (Posiva, 2021a). Currently STUK is reviving the application and has found insufficiencies in the long-term safety of the facility. STUK has requested further clarification from Posiva. STUK has announced that it will have statement concerning the operation license ready by the end of 2024 as the material provided by Posiva is extensive and requires time to review. (STUK, 2023)

3 KBS-3 concept.

Disposing spent nuclear fuel in DGRs is seen as the preferred option for passive multilevel barriers it offers. Spent fuel can emit harmful levels of radiation for hundreds to thousands of years, so a method of storing the waste in a facility which requires minimum to no supervision is preferable. Spent fuel stored in stable geological environment hundreds of meters below the surface is seen as the most feasible option that satisfies these requirements. (IAEA, 2003)

Posiva's GDR facility will use final disposal concept called KBS-3 (Kärnbränslesäkerhet-3) developed by Swedish company SKB. KBS-3 concept has two variations KBS-3V and KBS-3H the difference between the methods being in the orientation of the capsules. KBS-3V (v meaning vertical) is the method chosen by Posiva. In this method capsules are inserted vertically into the bedrock using holes drilled in the floor of the deposition tunnel (Figure 3.1). In KBS-3H method (h meaning horizontal) capsules are inserted horizontally into holes drilled on the walls of the disposal system. Posiva researched the possibility of using the horizontal method as it would decrease the number of tunnels that need to be excavated but ultimately decided on the vertical solution. (Palomäki & Ristimäki, 2013)

Figure 3.1 Deposition hole (Posiva. 2024d)

3.1 Primary safety feature

Safe disposal is based on maintaining favourable bedrock and groundwater conditions and constructing the disposal facility deep enough to be undisturbed by changes in climatic conditions and human activity (Palomäki & Ristimäki, 2013). Geological research done in the Olkiluoto area shows the bedrock to be geologically, mechanically and hydro chemically stable. In addition, the flow patterns of groundwater at different depths have been mapped as the groundwater flowing through the rock crevices are the only method for radioactive mater to get into contact with humans. This mapping allows for placing the disposal canisters in locations where there is little to no groundwater flow. (Posiva 2024e) (Posiva 2024f)

3.2 Multibarrier system

The KBS-3V concepts safety is based on multibarrier system. In this system there are multiple engineered or natural buffers act as radiation barriers, which all add to the safety of the system, and a failure in one of the barriers won’t cause a detrimental loss of functionality for the entire system. The barriers for the KBS-3V concept can be seen in figure 3.2. The fuel pellets within the fuel rods in solid state prevent the spreading of radio nuclides, they are stored within the disposal canister with is comprised of cast iron insert and external overpack. The canister is inserted into the deposition hole which is lined with bentonite buffer while the deposition tunnel is backfilled with bentonite granule. The canisters are located within the bedrock at 400–500-meter depth. The final closure of the facility which is not presented in the figure. (Palomäki & Ristimäki, 2013) (Posiva 2021a)

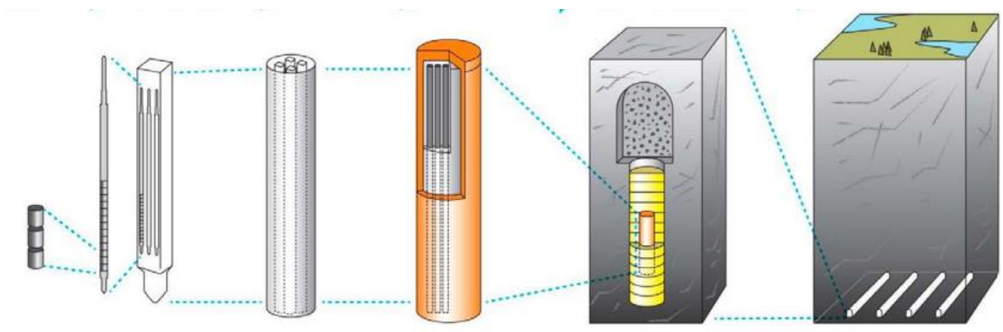

Figure 3.2 Barriers for the KBS-3V concept (Posiva, 2021a)

3.2.1 Disposal canister

The primary purpose of the disposal canister is to contain spent fuel for at least 10 000 years. It must prevent the escape of radionuclides and the entry of water. To achieve this the canister must have good corrosion resistance and withstand mechanical forces that it may be exposed to. (Palomäki & Ristimäki, 2013)

The canister is composed of two parts: from a nodular graphite cast-iron insert and a copper overpack. The insert’s main function is to protect the spent fuel from the mechanical loads it may be exposed to in the repository. It also provides shielding from radiation emitted by the spent fuel. The insert is also conductive, so heat generated by the radioactive decay is dissipated from the canister. To prevent and minimize corrosion happening within the capsule the air is replaced with inert gasses such as argon or helium before the cannister is sealed. Figure 3.3 has a copper overpack on the left and cast-iron insert for OL1 and OL2 reactor fuel rods. (Raiko, 2013)

Figure 3.3 Copper overpack and cast-iron insert (Posiva, 2024g)

The copper overpacks main function is to protect the insert from external corrosion. Material for it was chosen due to coppers good resistance to corrosion and other chemical processes it may be subjected to within the repository environment. Tests done to the copper overpack indicates that the corrosion depth after 10 000 years is only 30 mm, so the cannister can be expected to fulfil the requirements set for it. (Raiko, 2013)

There are three different variants of the disposal cannisters, for three different nuclear reactors in use, the dimensions of fuel rods being different for all the reactors. The diameter of the cannister is 1.05 m in all three variants. The differences between variants can be found in the length of the capsules and in the shape and placement of the openings for the fuel rods. (Raiko, 2013)

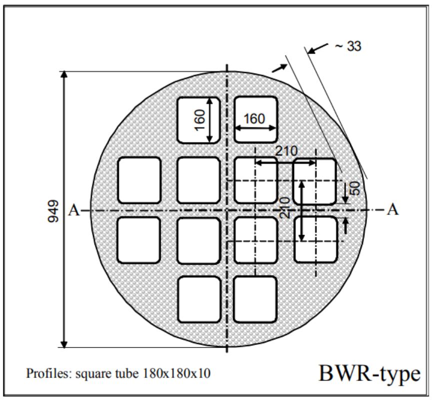

Figure 3.4 Cross-section of BWR-type canister insert (Raiko, 2013)

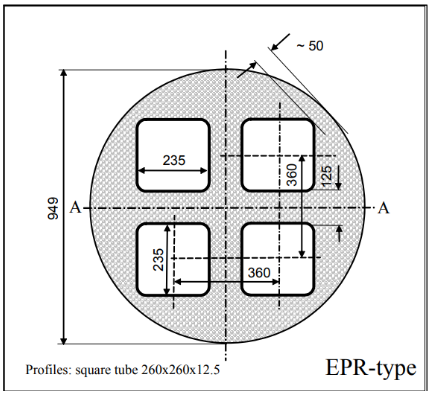

Figure 3.5 Cross-section of EPR-type canister insert (Raiko, 2013)

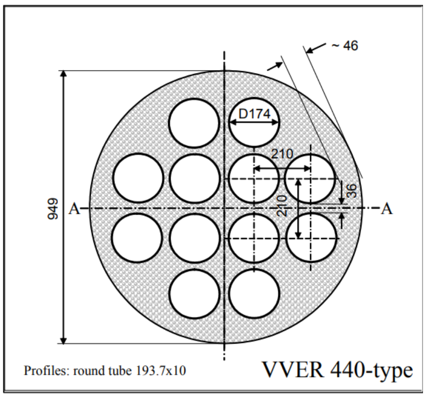

Figure 3.6 Cross-section of VVER-type canister insert (Raiko, 2013)

The variant created for VVER type reactors used in Loviisa is 3.55 meters long and weighs 18.8 tons. Fuel rods from BWR type reactors used in Olkiluoto are stored in canisters that are 4.75 meters long and weighs 24.5 tons. Final variant meant for rods used in EPR type reactor in use in Olkiluoto is 5.22 meters long and weighs 29 tons. The placement and shapes of the openings for fuel rods can be seen in Figures 3.4, 3.5 and 3.6, as seen in them the VVER and BWR type cannisters have space for 12 fuel rods in them, while the EPR type cannister can store only 4 rods. (Raiko. 2013)

3.2.2 Bentonite buffer

Deposition holes are lined with blocks of buffer material, and when the disposal canister is placed in the hole slabs of the buffer material is placed on top of it, the design of the buffer can be seen in figure 3.7. The main function of the buffer is to protect the cannister from detrimental external mechanical processes, prevent the transfer of corrosive substances to the cannister and create chemically favourable conditions, conduct heat away from the canister and slow the release of radionuclides in case of cannister failure. (Palomäki & Ristimäki, 2013) (Posiva, 2021b)

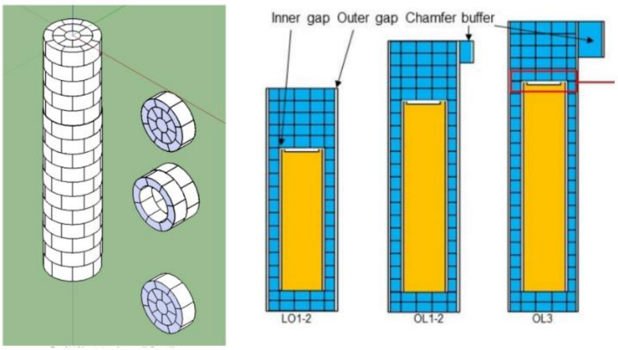

Figure 3.7 Desing of the bentonite buffer (Posiva, 2021b)

To fulfil the requirements set for the buffer the material should be elastic enough to dampen collisions caused by bedrock movement, but strong enough to support the cannister and hold it in place, as well as dense enough to prevent the movement of water through it and prevent microbial activity within the buffer. The best material that fulfils these requirements has been deemed to be bentonite clay. The type of bentonite in the operation license application is Wyoming-type high grade sodium bentonite. (Posiva, 2021b) (Palomäki & Ristimäki, 2013)

3.2.3 Backfill

After the disposal cannisters have been placed into the deposition holes, the entire disposition tunnel is filled. This backfilling process aims to return the conditions as close to a natural state as possible. The goal is to prevent the deposition tunnels from becoming new flow paths for groundwater, maintain the structural integrity of the tunnels, and prevent unauthorized access to the repository. Additionally, the backfill keeps the bentonite buffer in place and slows the release of radionuclides in case of canister failure. (Palomäki & Ristimäki, 2013)

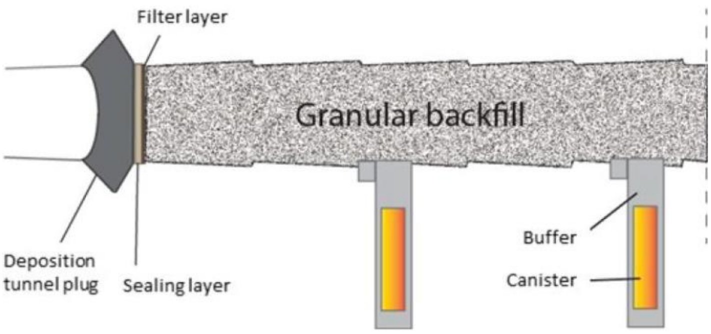

Figure 3.8 Desing of backfill (Posiva, 2021b)

The backfill is comprised of bentonite granules and sealing layer as seen in figure 3.8. The sealing layer is made of the same bentonite as the backfill and its pre-wetted during installation this prevents the movement of the granular backfill till the central tunnel is closed. The filter layer is a steel net with inorganic filter textile attached to it, its function is to spread the water on the entire tunnel profile area during pre-wetting. After the installation of backfill materials, the tunnel is closed with the tunnel plug, which is a concreate dome preventing the movement of the backfill. (Posiva, 2021b)

3.2.4 Bedrock

The bedrock is the main barrier that isolates the used fuel from biosphere and provides a stable and favourable environment for the other protective barriers. To ensure this deposition tunnel placement locations should avoid areas with significant bedrock fractures or high groundwater flow. Additionally, displacement tunnels should also be placed in chemically stable locations. (Palomäki & Ristimäki, 2013)

3.2.5 Closure of the facility

The closure of facility as a barrier refers to the backfilling access tunnels, central tunnels and other underground facilities required during the operation. This backfilling is done to stabilize the surrounding bedrock and prevent the openings from compromising the protective function of the bedrock. The backfilling also slows down the entry of harmful substances that might compromise containment of the spent fuel and prevents the formation of new flow channels for groundwater. The backfilling material used is a composition of rock and bentonite clay secured in place using concrete plugs (Posiva, 2021b). (Palomäki & Ristimäki, 2013)

4 Disposal site and the facilities

The Posiva final disposal facility is located on the island of Olkiluoto in the Eurajoki municipality. The site is comprised of underground and above ground facilities. Figure 4.1 illustrates the location of the site. The surface facilities can be seen in centre bottom and the Olkiluoto nuclear powerplant in the top right. (Saarnio et al., 2013)

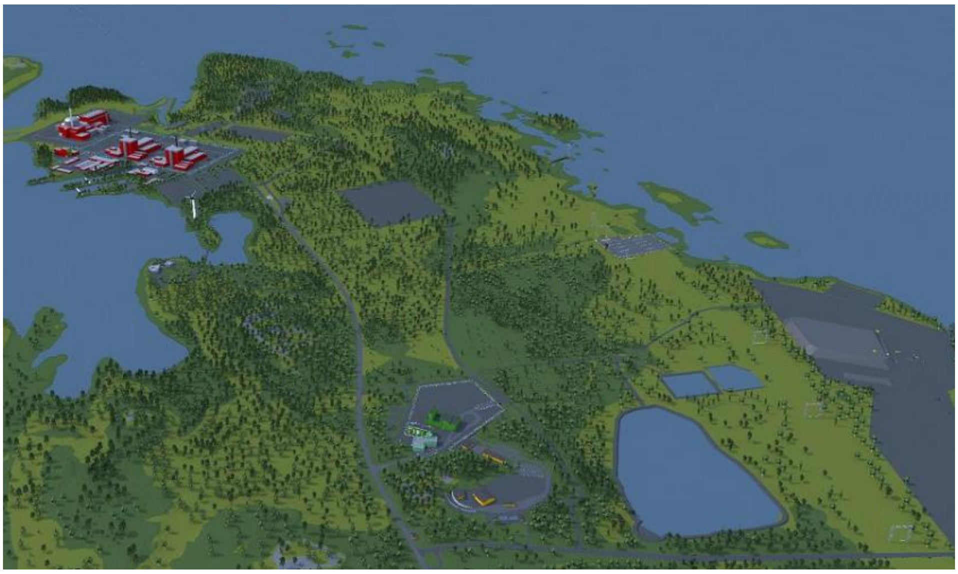

Figure 4.1 The location of the disposal facility (Saarnio et al., 2013)

During the construction and operation of the facility already existing infrastructure constructed for the nuclear powerplant is utilized to the maximum the electricity is supplied to the site by 20 kV cables from the nuclear powerplant substation. Water and sewage treatment is also supplied by the power plant. (Saarnio et al., 2013)

4.1 Encapsulation plant and other surface facilities

The encapsulation plant, where the spent nuclear fuel is received and loaded into the disposal canisters before being sent to the repository for disposal, is located on the surface of the facility alongside it there are multiple support buildings on the surface such as monitoring building, vehicle maintenance building and storages. (Saarnio et al., 2013)

4.1.1 Encapsulation plant

Encapsulation plant is located on top of the spent fuel repository. The plant receives the spent fuel and prepares it for disposal. The facility is equipped with all necessary tools for the encapsulation process. Additionally, it is equipped with canister lift for transporting disposal canisters to the repository, a workshop for equipment maintenance, a control room for process monitoring and a storage area for spent fuel awaiting repackaging into disposal canisters or awaiting transport to the repository. Bentonite slabs, used as buffer material in the disposition holes are also stored in the encapsulation plant. The slabs are sent to the repository using the canister lift. (Kukkola, 2012)

Figure 4.2 Longitudinal section of the encapsulation plant (Kukkola, 2012)

Spent fuel is received in its transportation caskets in the rightmost room seen on figure 4.2. From there the caskets are lowered into the casket transfer corridor where a trolly takes them under the fuel handling cell which is in figure 4.2 on the left side of the casket reception. Once the casket is under the fuel handling cell it's lifted and mounted on a docking station after which internal covering hatch of the fuel handling cell is opened and protective lids of the casket are opened and the fuel rods within the casket are removed and placed on drying docks as the spent fuel is loaded into the transportation caskets in water pools. (Kukkola, 2012)

Once the fuel rods have dried, they are loaded into the disposal canisters. New disposal cannisters are received in the same place as the transportation canisters. The new canister storage is located under the casket reception. From there the canisters are taken to the canister transfer corridor seen in figure 4.2 under the fuel handling cell. A transfer trolly takes the new disposal cannister under the fuel cell where they are lifted and docked to the fuel cell and covering hatch of the fuel cell is opened after which the fuel rods are placed into the canister. (Kukkola, 2012)

After the fuel rods are loaded into the cannister inner lid is placed on top of the canister and the air within is replaced with an inert gas. Once the inner lid is secured the covering hatch of the fuel cell is closed and the canister will be lowered back to the transfer trolly which then takes the canister to the welding chamber seen in figure 4.2 on the left side of the fuel handling cell. The canister is lifted to the welding chamber where outer copper lid is welded on the canister. Once the weld seams are machined and inspected the fuel encapsulation process is over, and the finished canisters can be transferred directly to the fuel repository using the canister lift seen in figure 4.2 on the left or stored in the canister buffer storage located next to the lift. The encapsulation plant should be able to produce around 40 canisters per year. (Kukkola, 2012)

4.1.2 Other surface facilities

The other surface facilities constructed at the site are the lifting equipment building, ventilation building, research building and storage hall, tunnel engineering building, maintenance hall, visitors’ centre and refuelling station. Site operations are monitored from the lifting equipment building it also houses the social spaces for the site personnel and personnel lift to the repository is in the lifting equipment building. Ventilation building provides ventilation to the underground parts of the facility with a singular intake shaft and with separate exhaust shafts for different parts of the facility. Research building and storage hall is constructed for the research and storage of borehole samples. Tunnel engineering building houses 20 kV transformer providing electricity to the repository, being located close to the shaft access it is also used to monitoring and control activities. Maintenance hall is used for the maintenance of drilling equipment and other machinery used within the tunnels it also has storage space as well as a vehicle washing hall. Visitors’ centre is shared by

Teollisuuden voima Oyj and it houses conference centre and exhibition spaces. Refuelling station is located close to the maintenance hall it supplies diesel fuel to underground facilities using service vehicles. (Saarnio, et al., 2013)

4.2 ONKALO and the disposal facility

The underground part of the disposal facility is comprised of spent fuel repository where HLW can be disposed as well as repositories for low- and intermediary level waste. The ONKALO research facility is used to gather geological data which is used to determine the layout of the disposal facility as well as provide information on the performance of the disposal concept. (Saarnio, et al., 2013)

4.2.1 ONKALO phase

Construction on an underground research facility began in 2004. During this phase, the facility was constructed at 420 meters. This space included research areas, storage and maintenance areas and technical rooms for communications, electricity, and the sprinkler system. Additionally, this level has a demonstration tunnel for testing disposal methods. More technical rooms are located at depth of 437 m for another electrical centre, sedimentation pool and a pumping station. At this level there would be also parking hall and a vehicle washing- and refuelling centre. At this phase the underground facility would be connected to the surface with two ventilation shafts and a personnel shaft. Along with a drive shaft allowing vehicles to enter the facility. (Saarnio, et al., 2013) (Posiva, 2008)

Before the operational phase the ONKALO facility is expanded with two additional shafts: a third ventilation shaft and a canister shaft. Included in the construction of the canister shaft is also excavating space for canister storage. ONKALO has been design in a way that repurposing the facility to operate as part of the disposal facility is as smooth as possible and space for the new additions to the facility was reserved already in the planning phase. (Saarnio, et al., 2013) (Posiva, 2008)

4.2.2 Underground disposal facility

The spent fuel is stored in deposition holes drilled in the floor of the deposition tunnels these holes and tunnels are collectively known as repository. These deposition tunnels are connected by central tunnels to entry shafts which connect the underground parts of the facility to the surface facilities. The spent fuel repository is in the depth of 400 to 450 meters while the low- to intermediary level waste repository is at the depth of 180 meters. (Saarnio et al., 2013)

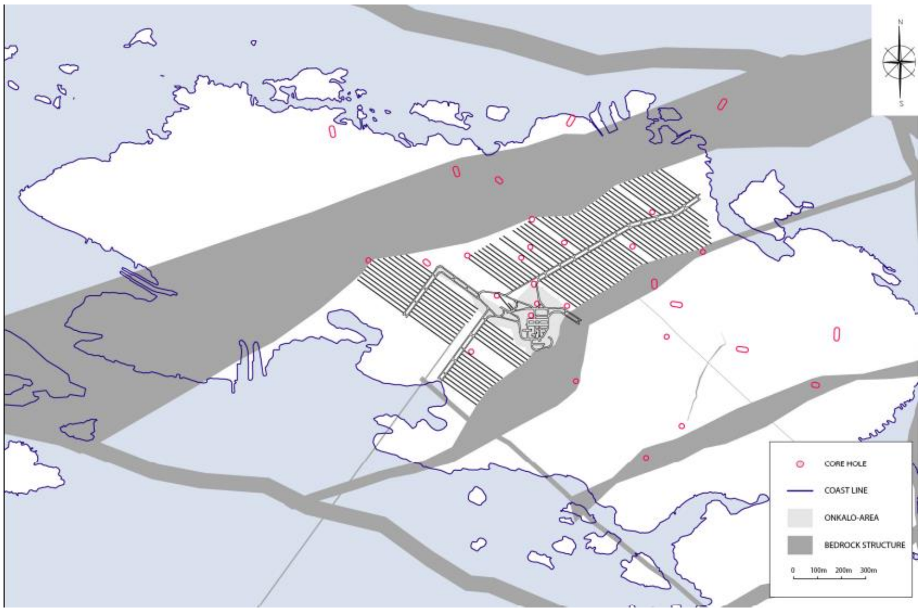

Figure 4.3 Layout of the underground facility (Saarnio et al., 2013)

Figure 4.3 illustrates the layout of the underground repository when 5440 tU of spent fuel has been disposed of. As much of the underground repository is built during the operational period this illustration is based on the current knowledge of the bedrock at the disposal depth. (Saarnio et al., 2013)

The narrower tunnels shown in figure 4.3 are the deposition tunnels which are 3.5 meters wide and 4 to 4.4 meters tall. A deposition tunnel can be up to 350 meters long, and minimum distance between two deposition tunnels is 25 meters. The wider tunnels that connect the deposition tunnels are called central tunnels. These tunnels are 6.4 m wide and 7.85 meters tall. The figure shows that they connect to a hub, the original ONKALO facility. The ONKALO area houses the drive, elevator and ventilation shafts. (Saarnio et al., 2013)

5 Operational period and closure of the facility

Once Posiva is given operation licence the DGR facility enters the operational period. During this phase the facility begins to receive spent fuel from the two Finish nuclear power plants and encapsules it in the disposal canisters and disposes it in the spent fuel repository. Alongside the disposal processes the underground facility is expanded by drilling for more disposal space for the spent fuel. Once the disposal process is at its end the facility will enter its closure period when the tunnels of the facility will be backfilled. (Saarnio et al., 2013)

5.1 Operational period

During the operations the underground facility receives disposals canisters from the encapsulation plant trough the canister lift. The canisters are taken stored in canister storage or taken directly to the deposition tunnels by a specialized transport vehicle which is also used to insert the canister into the deposition hole. Prior to the canister insertion the deposition hole has been lined with the bentonite buffer which is installed in the hole using its own specialized installation vehicle. Once all the disposal canisters that can be fitted into the deposition tunnel, it will be backfilled using granular bentonite clay mixture and plugged. (Saarnio et al., 2013) (Posiva, 2021b)

While the disposal operations are ongoing the facility will be gradually expanded. The step wise plan states that the central tunnels are excavated in campaigns to a pre-determined length while deposition tunnels are excavated continuously according to need. This approach has been adopted to limit unnecessary load open spaces may cause to the ventilation and seepage water pumping stations. (Kirkkomäki, 2013)

During operations the underground facility has been divided into controlled and uncontrolled areas. All handling of spent fuel happens in controlled are. Figure 5.1 illustrates controlled and uncontrolled areas at the ONKALO area. As seen in the figure the controlled and uncontrolled areas have their own ventilation shafts and electrical centres. The personnel shaft elevator has different compartments for employees going to controlled and uncontrolled areas. Division between the areas is to limit potential exposure to radioactive nuclides and the different areas also operate as fire compartments. (Saarnio et al., 2013)

While the controlled and uncontrolled areas shown in figure 5.1 are permanent trough out the operational period the tunnels are in controlled or in uncontrolled are based on, what is currently being done in them. Tunnels that are being excavated or backfilled are in the uncontrolled are, while deposition tunnels, and central tunnels leading to them, where insertions of disposal canisters or bentonite buffer is in progress. (Saarnio et al., 2013)

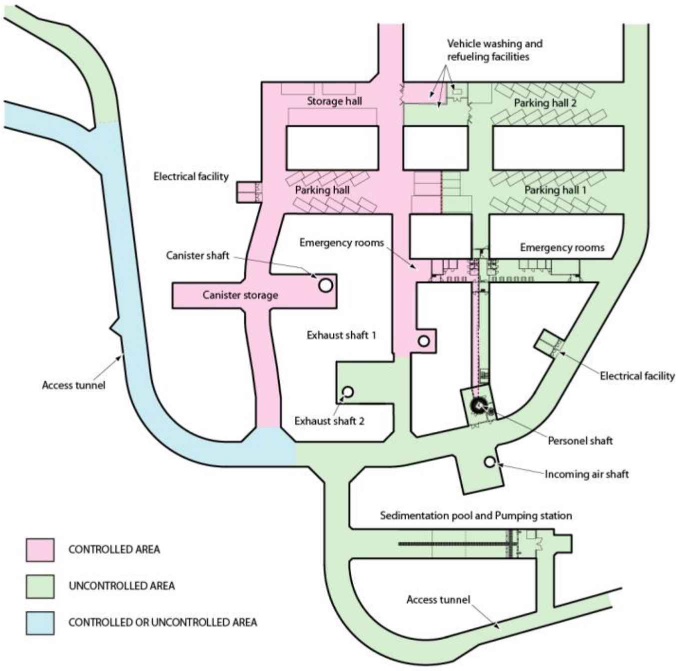

Figure 5.1 Controlled- and uncontrolled areas at the ONKALO area (Saarnio et al., 2013)

5.2 Closure of facility

At the end of the operational period there should be 6500 tU of spent fuel stored in 3304 disposal canisters, though Posiva has prepared to expand its disposal operations, where there would be 9000 tU of spent fuel stored at the facility. Currently planned 6500 tU of fuel should be disposed in 2107, after which the facility moves from the operation period into closure phase. The figure of 6500 tU of spent fuel is based on the estimates how much the currently running nuclear powerplants should produce waste during their lifetime. (Saarnio et al., 2013) (Posiva. 2021a)

Closure operations begin with dismantling work where all structures and systems utilized during the operations are removed, this includes the different electrical and communication systems, and floor tiles and concrete structures. (Saarnio et al., 2013)

After the dismantling work is done begins the backfilling of the facility. Most of central tunnels are backfilled during the operational period this process is brought to end. After all the central tunnels have been backfilled the ONKALO are and all entry shafts into it are also filled. The backfilling material used in this process is a mixture of bentonite clay and rock material. The backfilling material is secured in place using mechanical plugs at regular intervals. These mechanical plugs are made of concreate and are similar in design to the plugs used in the deposition tunnels. In addition to the mechanical plugs there are also hydraulic plugs which are made of bentonite, which purpose is to prevent water flow through them. Finaly once the backfilling process has reached the surface intrusion obstructing plugs are placed on the entry to the access shafts. These plugs are made of concreate and natural stones. This backfilling process is intended to finalize the isolation of the spent fuel and preventing any radioactive material to migrate back to the surface. (Saarnio et al., 2013) (Posiva. 2021b)

6 Summary

The Posiva's DGR facility's construction began in 2004 with the underground research facility ONKALO. Prior to the construction Posiva had done extensive research into the bedrock of multiple potential locations, but ultimately the island of Olkiluoto was chosen. The construction work needed to begin operations was concluded in 2021 when Posiva applied for operation licence. The licence is currently under review by STUK, which should have statement ready by the end of 2024.

The Posiva DGR operates as a final disposal site of spent fuel generated by the two Finish nuclear powerplants the facility won't receive any fuel from any foreign plants as the current legislation forbids exportation and importation of nuclear waste.

The method used in the disposal of spent fuel is named KBS-3. This method is based on isolating the waste in stable conditions using multiple barrier method. This method prevents the entire system from losing its primary function in case of failure in one of the barriers. The main release barriers in KBS-3 method are the disposal canister, bentonite buffer, tunnel backfill and the bedrock.

The facility itself is comprised of surface and underground sections. On the surface there is the encapsulation plant which seals the fuel rods into the disposal canisters and sends them to the repository. Along with it on the surface there are multiple support facilities such as research laboratory and storages. The underground parts are comprised of the ONKALO area and the spent fuel repositories which are connected to the ONKALO by central tunnels. The ONKALO is connected to the surface with ventilation and access shafts.

During the operational period disposal canisters are received from the encapsulation plant at the canister storage room in the underground facility where they are moved to the fuel repositories trough the central tunnels. Alongside the disposal operations the facility will gradually expand. Deposition tunnels are excavated according to the need, while central tunnels are excavated in campaigns. During this period the exposure to the radiation emitted by the spent fuel is limited by dividing the facility into controlled and uncontrolled areas, where the handling of spent fuel is only allowed in the controlled areas.

After the operational period is finished there should be around 6500 tU of spent fuel stored in the facility. This number is based on the waste generated by the two currently running nuclear power plant in their lifetime. After all the waste has been placed in the repositories the facility will enter closure period when all the underground facilities will be dismantled and backfilled using bentonite rock mixture. Along with the backfilling material, multiple plugs will be placed in the tunnels to secure the backfilling material in place and to prevent any waterflow trough the backfill.

7 Conclusions

Posiva's DGR facility is first of its kind in the world and it's Finish states solution to the problem of spent nuclear fuel. The facility is built in geologically stable area and Posiva has done research into the conditions of the bedrock to plan the layout of the underground facility in a way that prevents disposal canisters from being placed too close to weak points in the bedrock or ground water flow paths. The disposal method itself uses multiple release barriers to prevent radioactive material from coming into contact with humans, and these barriers are designed to last at least 10 000 years. During the operational period the contact with spent fuel has been limited by having the handling of spent fuel being performed in isolated spaces. All these factors indicate that Posiva has a sound plan for the disposal of spent fuel that takes the safety of employees as well as the public into consideration.

At the moment Posiva has applied for operation license, which is now under review by STUK, which had found the plans for long term safety to be insufficient, this on the surface does seem concerning, however Posiva was able to provide clarification requested by STUK, which indicates that the issues were insufficiencies in the provided documentation and not due to insufficiencies in the safety of the facility. STUK should have a review of the material provided by Posiva ready by the end of 2024 and then we will see, if there'll be further delays or will the world's first disposal site for nuclear fuel begin operations in 2025.

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