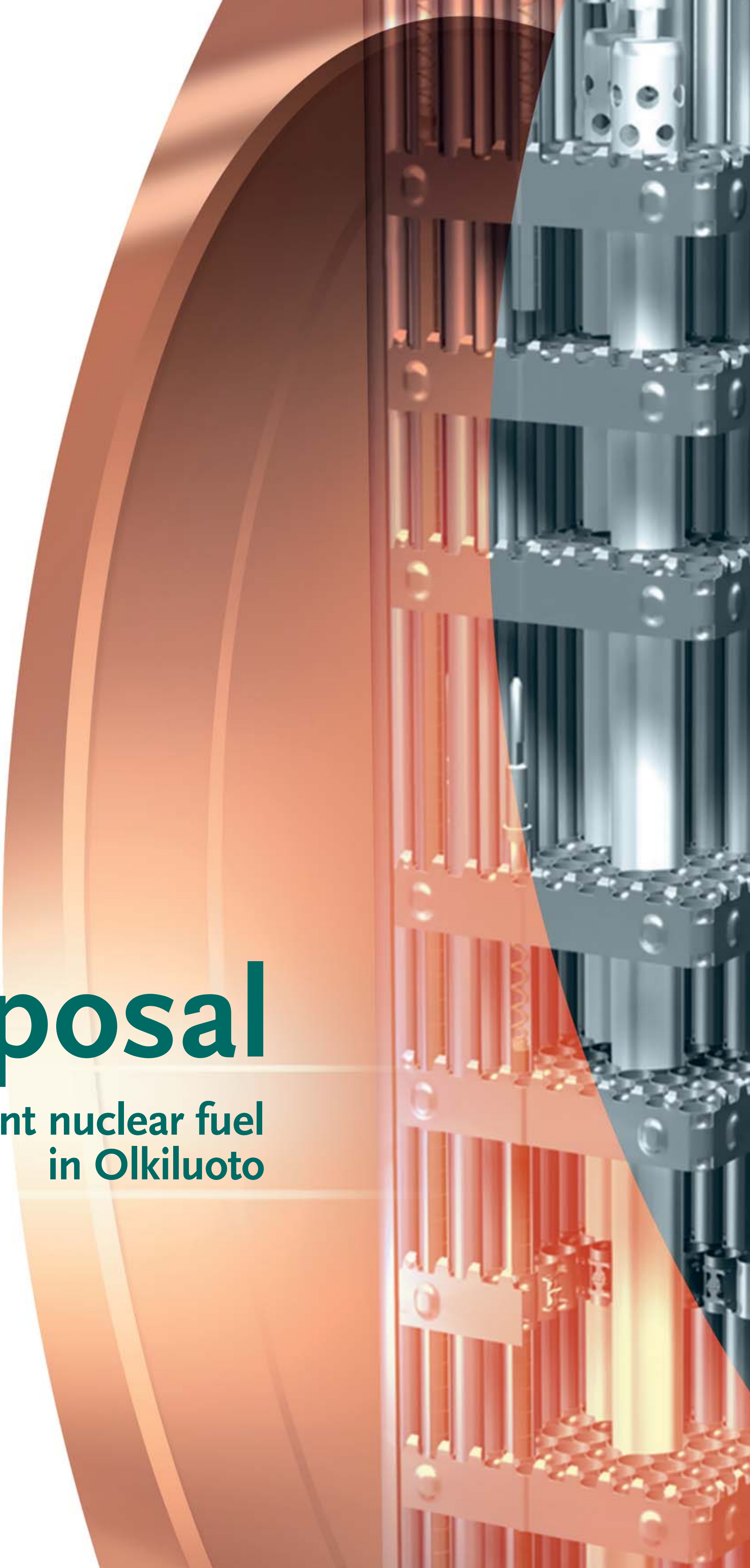
POSIVA

Final disposal

of spent nuclear fuel in Olkiluoto



Safe management of spent nuclear fuel

The production of nuclear electricity generates radioactive waste, which has to be taken care of with particular attention. In responsible waste management, radioactive waste is isolated so as not to cause harm to the people and environment. In Olkiluoto and Loviisa nuclear power plants, approximately 70 tonnes of spent fuel is accumulated per year. As the planned service life of a nuclear power plant unit is 50–60 years, the approximate total of spent fuel from the Olkiluoto and Loviisa nuclear power plants, including Olkiluoto 3, which is under construction in 2011, is 5,500 tonnes.

This brochure covers the maintenance and final disposal of spent nuclear fuel from the Olkiluoto and Loviisa nuclear power plants.

What is spent fuel like and how is it handled?

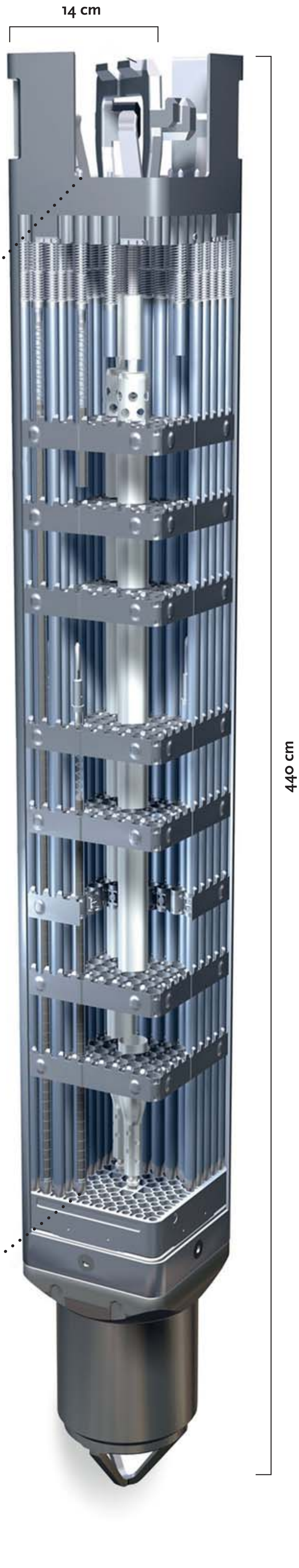
Annually, a number of fuel bundles are removed from the reactor core and replaced. These bundles, which have delivered their energy, account for up to one-third of the total number of bundles in the reactor. Fresh fuel bundles can be handled manually, but spent fuel bundles must be handled with a remote-controlled device from behind a radiation shield. The required protection can be either a one-metre thick concrete wall or a few metres of water. Spent nuclear fuel is radioactive and also produces extensive heat, which must be accounted for in handling and storage.

After use, the composition of the fuel pellets has changed. About 96% of the contents are still uranium as it was in the fresh fuel and about 3% of the uranium in the rods has split during the use into lighter fission products. The rest, 1%, is plutonium, formed through the neutron capture reaction, and other elements heavier than uranium, i.e. transuranic elements.

After removal from the reactor, the spent fuel radiates powerfully. Eventually, the uranium and the fission products and transuranic elements decay further, finally into non-radioactive elements. Some elements only take a few seconds to decay, others need billions of years.

After a few years of cooling in the reactor hall's water pools, the spent fuel bundles are transferred to an interim storage in the power plant area. The spent fuel is cooled for at least 20 years before disposal.

TVO nuclear power plant in Olkiluoto and Fortum nuclear power plant in Loviisa.



The pellets are stacked one after another in zirkonium alloy tubes to form approximately four-metre fuel rods that are as thick as a human finger. One fuel bundle usually contains 60–100 rods.

Uranium fuel pellets are specifically designed for reactor conditions: the pellets are ceramic and endure high heat levels. Most of the long-lived radioactive substances are tightly bonded to the uranium.

Geological isolation

Where time stands still: The Finnish bedrock in the Olkiluoto area is over 1.8 billion years old and has remained in the same condition for millions of years.

In the geological disposal, the spent fuel bundles are isolated into bedrock so that the disposed uranium fuel will not cause harm to living organisms under any circumstances. Since the impact of changes above ground only extends to the shallow parts of the bedrock, a sufficient depth will ensure stable and predictable conditions in the repository. The depth will also eliminate the possibility of people unintentionally intruding into the deposition tunnels.

The isolation has to be effective far into the future, since the radioactivity of the spent fuel is comparable to natural uranium deposits only after 100,000 years.

Multibarrier system ensures safety

The geological disposal concept is based on a multibarrier system to isolate the spent fuel from biosphere. This isolation system consists of engineered and natural barriers and is called KBS-3 (KBS, Kärn Bränsle Säkerhet = nuclear fuel safety). The barriers are: bedrock, tunnel backfill, bentonite buffer and disposal canister.

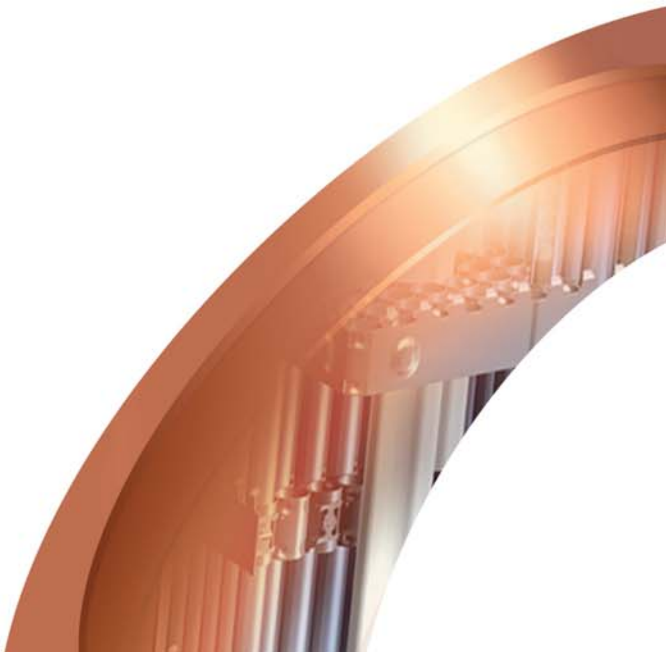
The disposal canister consists of a 5 cm thick copper overpack and a cast-iron insert containing the fuel bundles.

Geological mapping of the bedrock at the final disposal site in Olkiluoto.

Bedrock

Finnish bedrock is old and stable: for example in the Olkiluoto area, the bedrock is over 1.8 billion years old. Lithosphere-forming processes that may cause volcanic activity, large bedrock movements and major earthquakes stopped having an impact on the bedrock hundreds of millions of years ago. Based on extensive research, it is known that minor bedrock movements can take place in the existing fracture zones. The bedrock between them has remained in the same condition for millions of years, and changes to the rock surface have mainly been caused by climate changes and glaciation.

Processes deep in the bedrock take place slowly and are fairly well predictable over long periods of time. In practice, water occurring in rock fractures is the only agent that could cause changes to the multibarrier system. Based on detailed studies, it is known that groundwater found deep in the bedrock is void of oxygen and moves very slowly. When the groundwater moves slowly in the rock fractures, it reacts with the surrounding minerals and a predictable chemical balance is established between them.



Disposal canister

To prevent the possible impact of the groundwater on the fuel bundles, the bundles are packed in protective canisters.

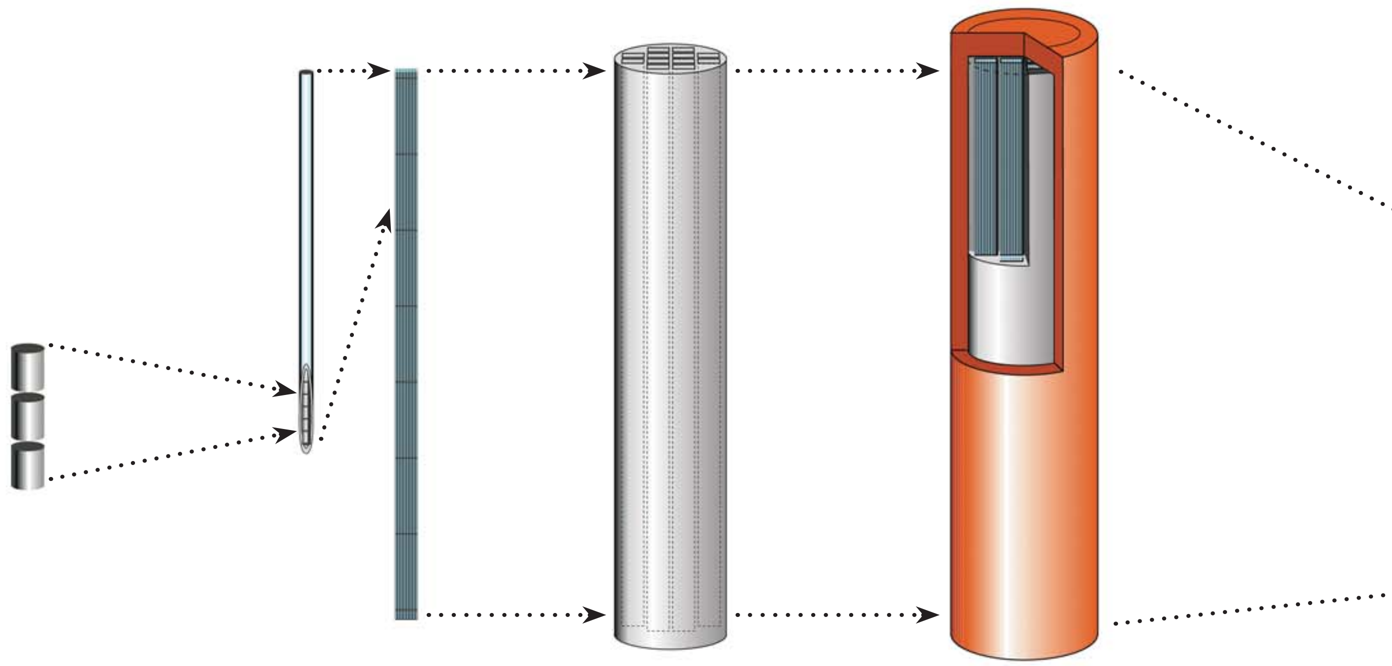
The canister's inner part is made of strong cast iron. Its task is to ensure the mechanical strength of the canister. The strength has been specified by taking into account that a glacier, many kilometres thick, can multiply the groundwater and the bedrock pressure in the future. The outer shell of the canister is made of corrosion-resistant copper that withstands oxygen-free conditions in the bedrock.

Bentonite buffer and tunnel backfill

Bentonite clay buffer acts as a protective wall, isolating the canister from the surrounding rock. The clay will swell in contact with water, fill all empty space and prevent water from moving around the canister.

The canister and its bentonite buffer will be installed in a deposition hole. The vertical deposition holes are bored in the floors of the deposition tunnels. The tunnels will be backfilled with blocks of clay to ensure that the canisters and their bentonite protection will remain in place in the deposition holes and that there is no water flow. The tunnel backfill will help restoring the conditions prevailing before excavation.

Several release barriers back up each other and ensure long-term safety

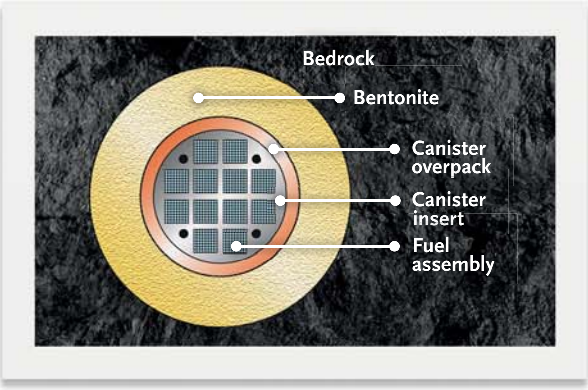


Fuel pellet
The uranium of the spent fuel is in a ceramic form which dissolves slowly.

Fuel assembly
The fuel pellets are enclosed in gas-tight, highly corrosion resistant fuel rods made of zirconium-based alloy.

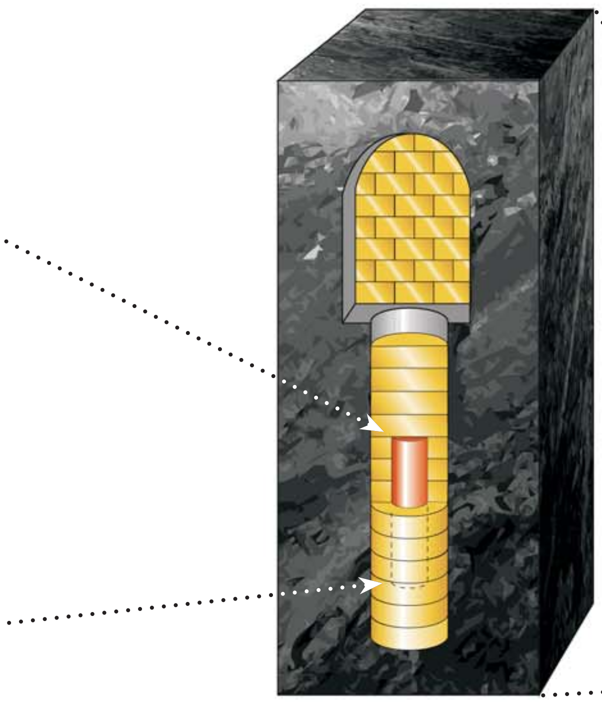
Canister insert
The canister insert houses the fuel assemblies. The insert is made of nodular cast iron and ensures the mechanical strength of the canister.

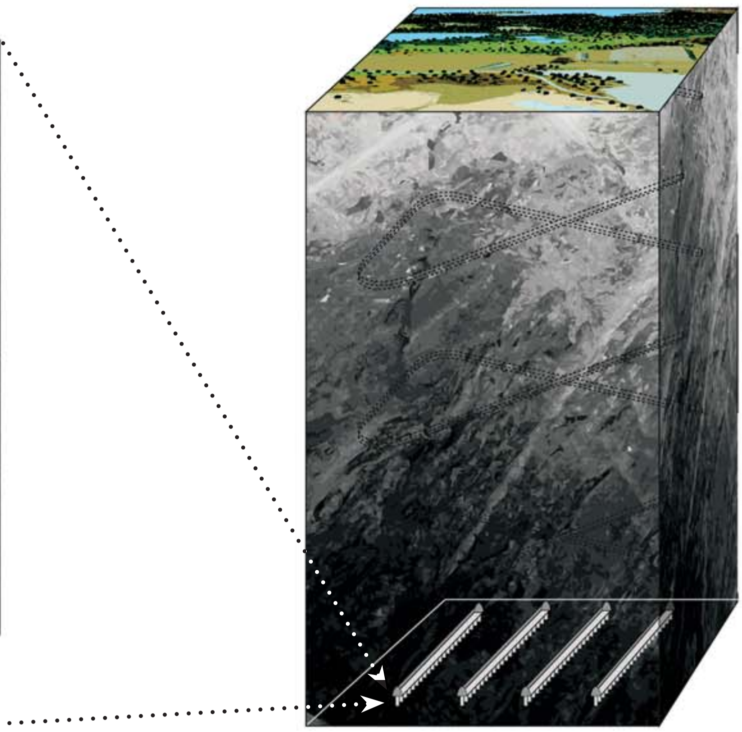
Canister overpack
The gas-tight canister overpack is made of copper, which is highly corrosion-resistant in oxygen-free conditions.



Several release barriers enclose the disposed fuel (horizontal section).

Installation of bentonite in a test deposition hole.





Bentonite buffer

The canister is emplaced in a deposition hole, which is filled with bentonite blocks. The bentonite swells when it comes into contact with water and prevents water movement around the canister.

400–500 metres of bedrock

isolates the disposed fuel from the living environment. Placing fuel at this depth will prevent terrestrial changes from affecting the surroundings of the disposal canisters.

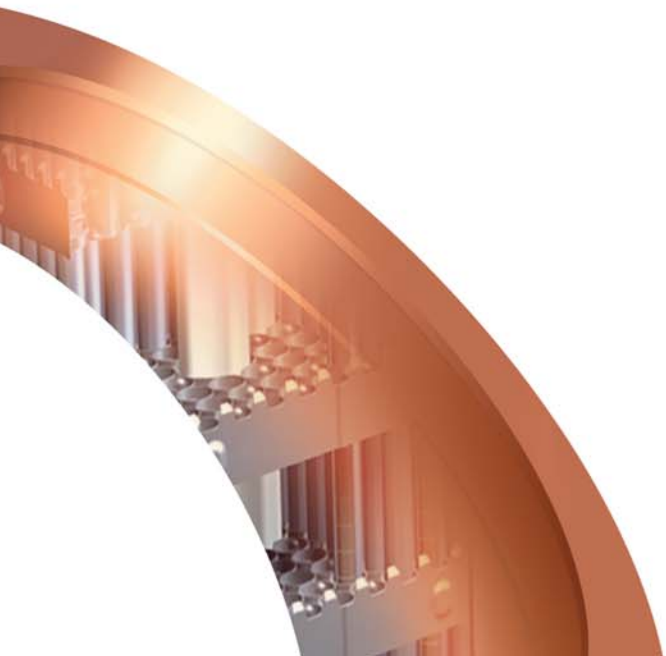
How is the geological disposal carried out in practice?

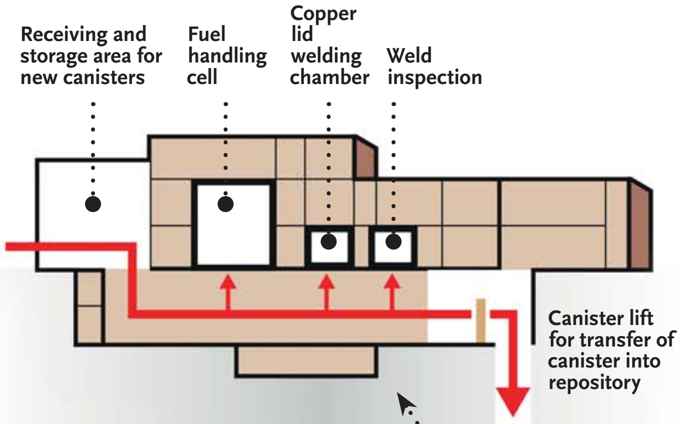
After several decades of interim storage, the spent fuel bundles are packed in canisters in an encapsulation plant. The fuel bundles are transferred from the interim storage to the encapsulation plant using a collision-proof transport container that prevents damage to the fuel bundles during transport and also acts as a radiation shield. From the interim storage in Loviisa, the fuel can be transported either by road, by rail or by sea to the disposal facility in Olkiluoto. The principal concern in transportation is that transport casks must not lose their radiation protection capacity even in the worst conceivable accidents. In the encapsulation plant, each disposal canister is filled with protective gas to keep the internal corrosion caused by humidity and radiation insignificant.

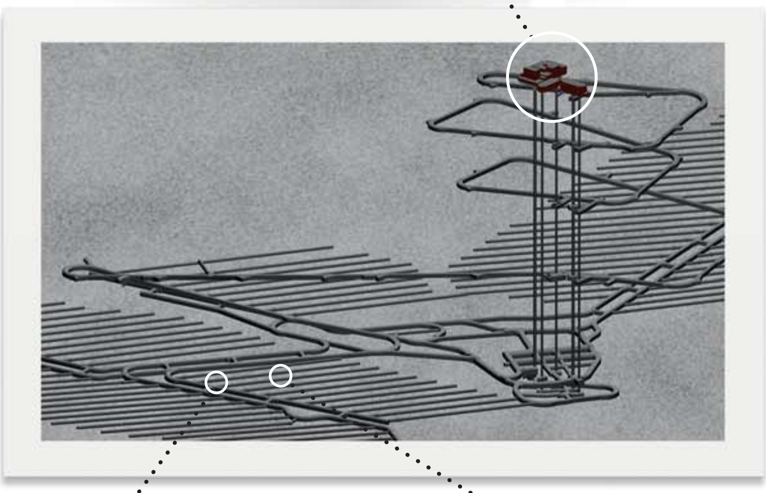
From the encapsulation plant, the 20-tonne spent fuel canisters are transferred by the lift down to the repository where they are transported by a designated vehicle to the deposition tunnels and installed into vertical deposition holes.

A layer of bentonite is emplaced around the canisters. Bentonite is clay that absorbs water and swells extensively. The swelling is further intensified by compressing the clay to hard blocks. The swelled bentonite efficiently insulates the canister's surroundings and prevents groundwater flow on the canister surface.

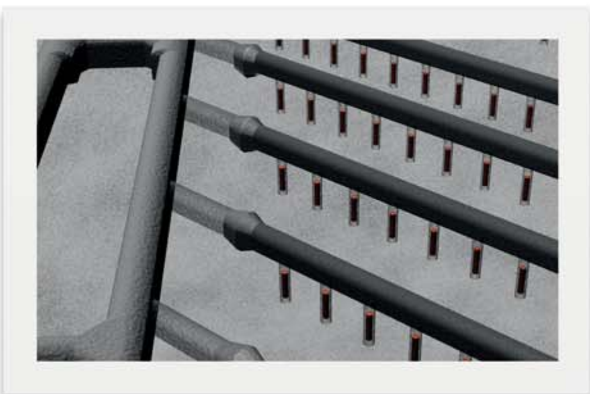
After the canisters have been installed in deposition holes, the deposition tunnels are backfilled with pre-compacted clay blocks. At the end of the disposal operations, the technical facilities, the central and connecting tunnels and the shafts will also be backfilled with crushed rock and bentonite.



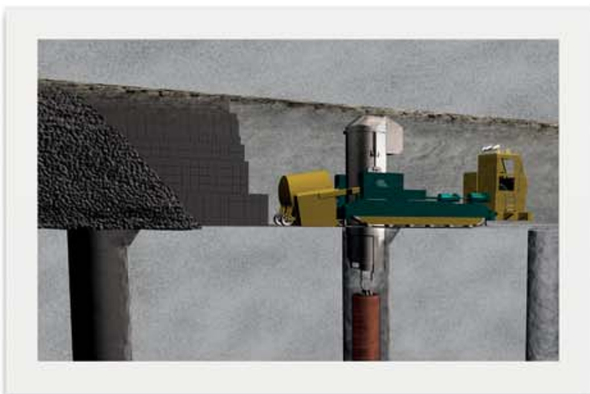




The lay-out for final disposal facility in Olkiluoto. The coverage area of the underground repository is 1.5–2 km².



Deposition tunnels, where the canisters are emplaced in deposition holes bored in tunnel floors.



A disposal canister will be emplaced in a bored hole and surrounded with highly compacted bentonite clay blocks. The deposition tunnel will also be backfilled with pre-compacted clay blocks.

Effects of glaciation on the bedrock conditions are studied in Greenland.

Only safe disposal is feasible

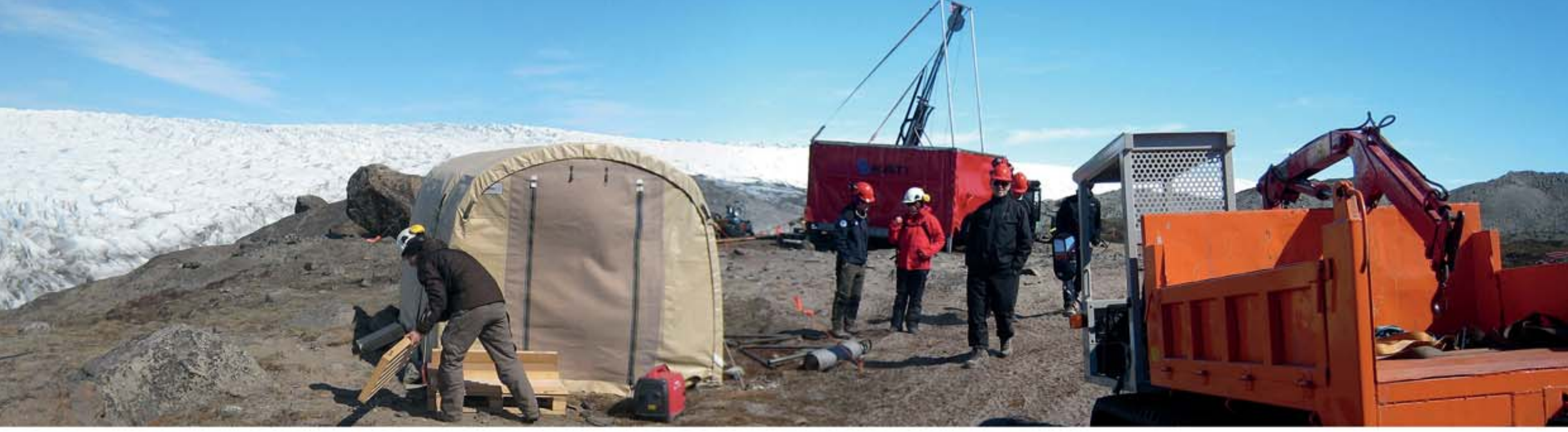
Safety case demonstrates the long-term safety

A safety case will be prepared for the purpose of demonstration of the long-term safety of disposal of spent nuclear fuel. According to an internationally adopted definition, "safety case" refers to all the technical-scientific documentation, analyses, observations, tests and other evidence that are used to substantiate the safety of disposal and the reliability of the assessments thereof.

Within safety case the features of the repository site and the technical properties of the disposal system as well as the future development of external factors having an impact on the disposal, particularly climate conditions will be analyzed.

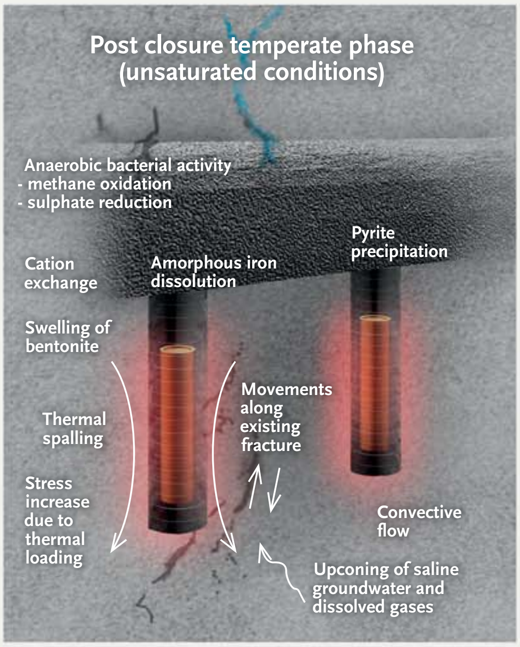
The scenario analysis is the key part of the safety assessment. The analysis evaluates the behaviour of the disposal system, installed deep in the bedrock, on the basis of assumed series of events. The assessments extend far into the future and account for the following changes in circumstances: climate change and a formation of a thick glacier and the possible occurrence of post-glacial rock movement.

The performance targets and target properties defined for the disposal system form one starting point for the safety case. The design basis scenarios relevant to the disposal environment determine the preliminary performance targets assigned to the engineered barriers. This means



Suitable geological environment for disposal
(required by safety concept and practical implementation)

- » **Long-term (millions of years) geological stability, in terms of major earth movement and deformation, faulting, seismicity and heat flow**
- » **Small groundwater flux at repository depths**
- » **Stable geochemical or hydrochemical conditions at depth (geochemical system maintains reduced and neutral ground water conditions)**



Main processes in the canister near field after the closure of the repository.

that as long as the targets are met in most canister locations, the safety requirements for the disposal will be met with high confidence, in spite of some possible incidental deviations. The rock immediately surrounding the repository has, for its part, been assigned preliminary target properties that form a basis for the rock suitability criteria (RSC) to be employed in the selection of the deposition tunnel and hole locations.

One area of safety assessment is modelling the chemical quality of the groundwater and its flow in rock fractures. These studies tell about the behaviour of the bentonite clay and the canisters in the course of time. Safety assessments prepared so far have further strengthened the conception of disposed canisters remaining intact for hundreds of thousands of years. However, the possibility of a decrease in the isolation capacity of some canisters during ice ages cannot be fully ruled out. Careful calculations related to radioactive substances dissolving in the groundwater and travelling along with it indicate that even in such a case, it is highly probable that the impacts above ground will remain lower than the limit values specified by the authorities. In addition, when preparing such calculations, worst-case scenario initial values must be used, and they exaggerate the impact.

Research and development for disposal

The main goal of the research and development is to ensure a safe permanent solution for spent fuel management. Firstly, sufficient information for confirming the suitability of the Olkiluoto bedrock for disposal is being obtained. Secondly, the disposal system is being developed to perform safely in the Olkiluoto bedrock conditions.

Above ground site investigations

Site investigations related to the disposal of spent nuclear fuel have been carried out in Olkiluoto ever since the 1980s.

The original purpose of the site investigations was to produce information to underpin the selection of the disposal site. Since Olkiluoto was chosen as the disposal site, the site investigations have continued, now with the aim of ensuring Olkiluoto's suitability for final disposal. The investigations provide information for the planning and designing of the repository, the assessment of the long-term safety as well as the construction of the ONKALO.

One of the major site investigation means is to drill deep drillholes that can be used for various geological, geohydrological, geochemical and rock mechanical investigations. Other important methods are excavating investigation trenches for geological studies and conducting variable geophysical examinations. The surface environment, including the flora and fauna, is also actively studied.

Underground investigations

An important element of the site investigations conducted at Olkiluoto is the construction of the underground rock characterisation facility ONKALO.

ONKALO aids in collecting further data needed for the construction licence application that will be submitted in 2012. The bedrock and its geological, hydrological and geochemical properties are studied.

In addition to facilitating bedrock research, ONKALO also provides an opportunity to test and demonstrate processes for assessment of rock suitability, design of repository tunnels and their excavation.

ONKALO will later serve as an access to the repository. The access tunnel has been excavated by the conventional drill and blast method with

Investigation site for final disposal in Olkiluoto. More than 50 deep drillholes have been drilled in the area since the late 1980's.

Drilling of a research hole at Olkiluoto investigation site.

an inclination of 1:10, which means that the length of the access tunnel will be more than 4 km. Concurrently with the tunnel excavation three raise bored vertical shafts are being constructed for ventilation and personnel lift. The construction methods and materials have been selected in order not to jeopardise the long-term safety of the repository site. The excavation of the access tunnel was started in 2004 and it reached the target depth in 2010.

Objectives of underground rock characterisation

» **Confirmation of the conclusions on site suitability**

» **Developing the methodology for locating suitable rock volumes**

» **Developing construction and excavation methods**

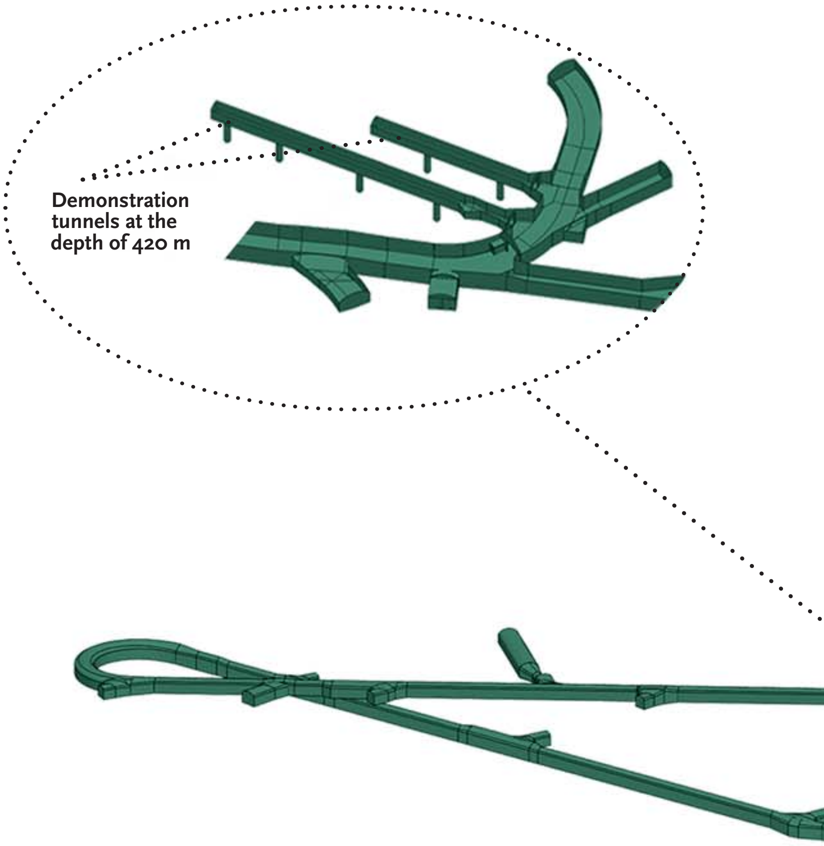
» **Testing and demonstration of repository technology in actual conditions**

Demonstration tunnel in ONKALO at disposal depth.

Experiment in a test hole to study the spalling strength of Olkiluoto rock in ONKALO.

Drilling jumbo used in ONKALO excavations.

Canister emplacement test in Äspö hard rock laboratory in Sweden.

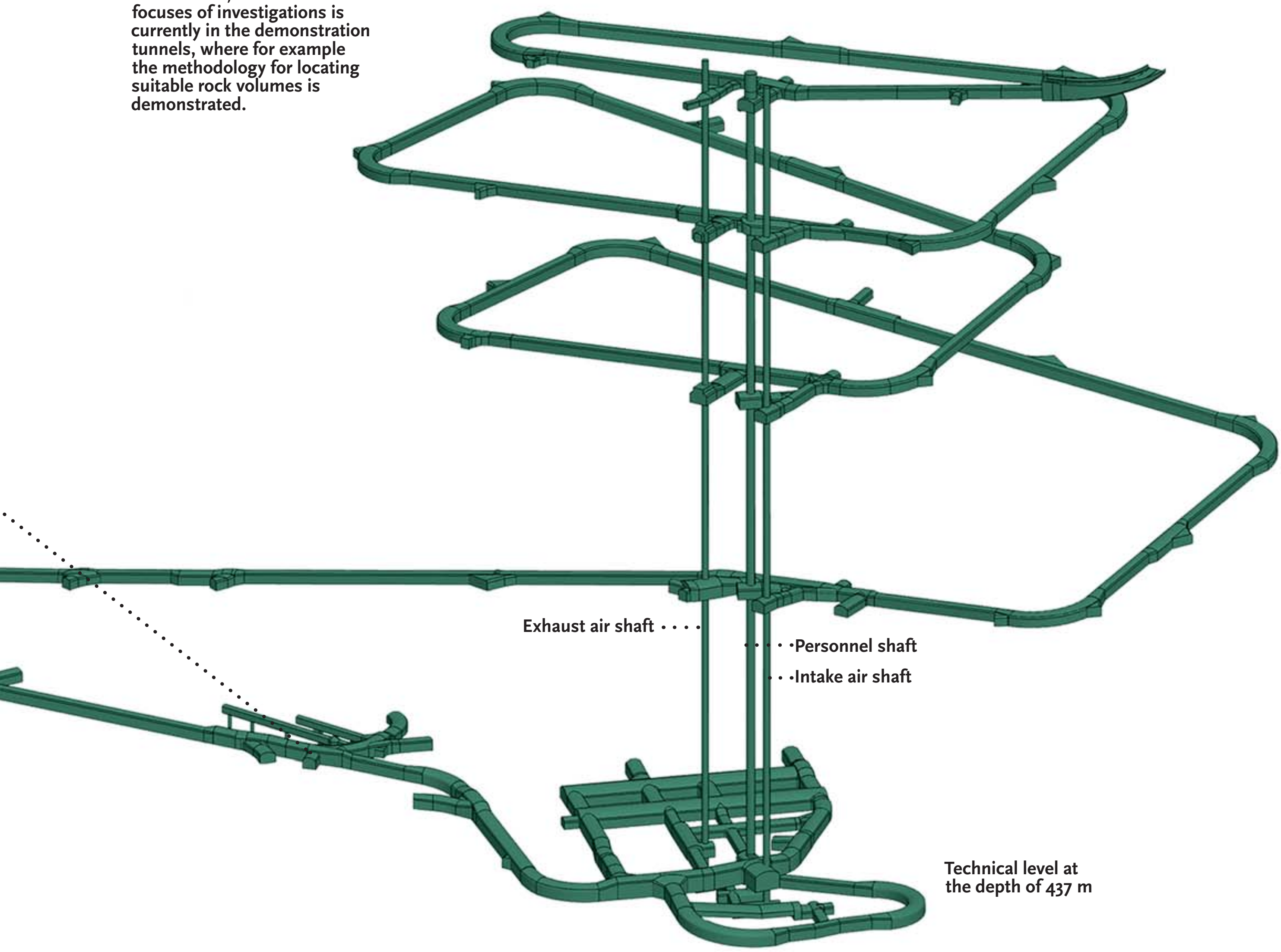


Research and development for the final disposal system

Technical R&D efforts focus on the disposal system. The disposal system – the disposal canisters, the bentonite clay in which the canisters are enclosed as well as the backfill material of the tunnels – play an essential role in safe disposal.

The research and development efforts focusing on the disposal system is to a great extent carried out in cooperation with the Swedish nuclear

In ONKALO, one of the main focuses of investigations is currently in the demonstration tunnels, where for example the methodology for locating suitable rock volumes is demonstrated.



fuel management company SKB (Svensk Kärnbränslehantering Ab). The techniques studied for the fabrication of the external copper canister include pierce and draw-method, extrusion and forging. Electron beam welding and friction stir welding are tested as alternative methods for sealing the canister. Various non-destructive methods are developed for the inspection of the canisters.

Apart from the canisters, technical R&D efforts encompass also the bentonite used as buffer material in the deposition holes as well as the clay used as backfilling material in the tunnels. For bentonite, it is important to study the impact of heat, water and mechanical stresses on the material. The manufacture and installation of the bentonite blocks for the deposition holes are also important development areas.

The schedule
for disposal

The properties of Finnish bedrock have been surveyed on a general level with regard to final disposal since the beginning of the 1980s. Research on final disposal technology, especially R&D work on the manufacture and sealing of final disposal canisters and studies related to long-term safety, were also initiated at that time.

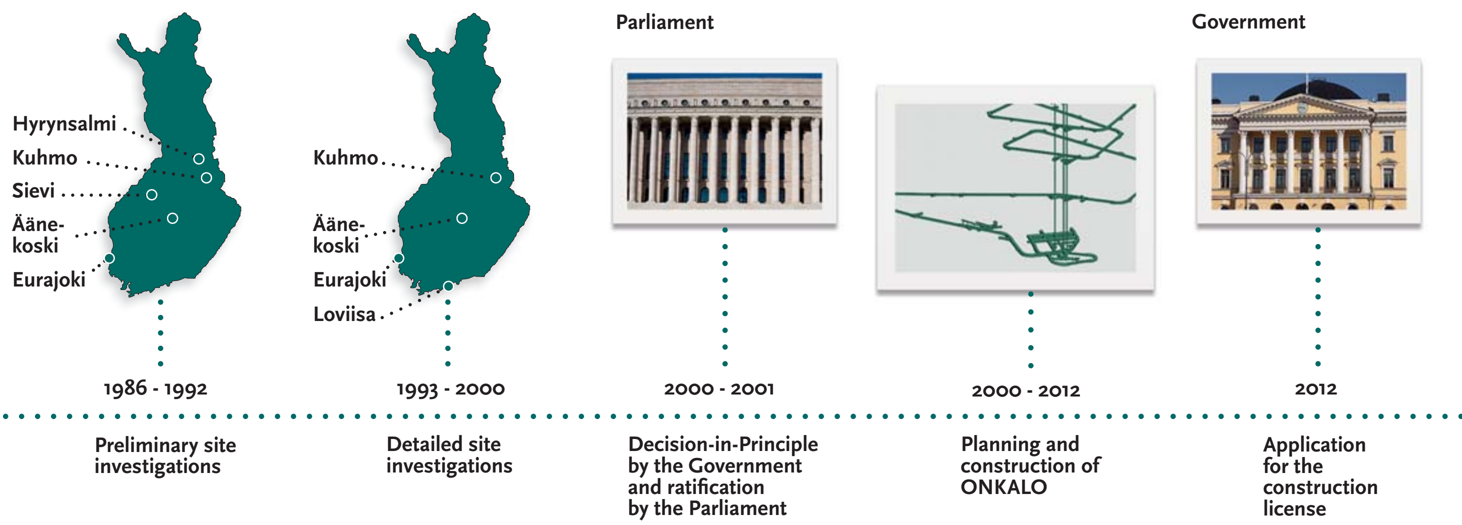
Since 1986, the field surveys have aimed at clarifying the properties of bedrock suitable for the final disposal of spent nuclear fuel, first on five locations and, since the 1990s, on four target areas, including Olkiluoto at Eurajoki.

Based on extensive site investigations, Olkiluoto site in Eurajoki municipality was selected for final disposal in 1999 in Posiva's application for the decision-in-principle to the Government. The Government made the decision in 2000 and Parliament ratified this decision in 2001.

To verify the results from the site investigations Posiva decided to construct the underground research and rock characterisation facility ONKALO. The intention is that ONKALO would be later part of the repository as an adit.

Posiva will submit the construction licence application in 2012. After the construction licence, the next major mile stone is the operating licence, scheduled for 2020.

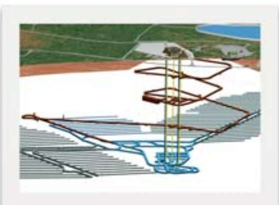
Preparations for final disposal have proceeded following the overall schedule set by the Government in 1983: The aim is to start final disposal in 2020.

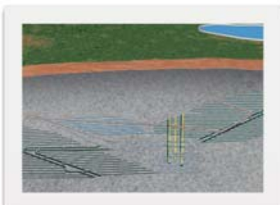


Rationale for selection of Olkiluoto

- Based on the site evaluation and safety assessment Olkiluoto is suitable for final disposal
- According to Environmental Impact Assessment, implementation of the project has primarily neutral or positive effects in Eurajoki municipality
- Majority of the local people approve final disposal project
- Higher degree of flexibility for construction due to the larger land area
- Smaller need for transportation, because most of the spent fuel already exists at Olkiluoto

Government





2015

Start of the construction of the final disposal facility

2020

Operation license from the Government, start of disposal

2120

Closure of the repository

Decision-in-Principle

When licensing a nuclear facility in Finland, the first step for the licensee is to apply for the Decision-in-Principle (DiP) from the Government. The purpose of the DiP is to judge whether the construction of a nuclear facility is in line with the overall good of the society. The preconditions for the favorable decision by the Government are:

Approval by the regulator (Radiation and nuclear safety authority STUK): STUK's review has not brought out any factors that indicate that the safety requirements can not be met.

Approval by the municipality: the intended municipality for nuclear facility has a veto right. For favourable decision, the municipality has to support the DiP.

Legislation and funding

According to the Nuclear Energy Act, nuclear waste generated in Finland must be handled, stored and permanently disposed of in Finland.

Waste management obligation rests with the power companies

The responsibility for nuclear waste management lies with the nuclear power companies, who must take care of the measures associated with the management of the nuclear waste they have generated, and bear the costs for these measures. The Finnish power companies with nuclear waste management obligation, TVO and Fortum, have assigned the duties related to the disposal of spent nuclear fuel to Posiva Oy, which they jointly own.

The responsibility of nuclear power companies extends to the time the nuclear waste is considered permanently disposed of according to law. The Ministry of Employment and the Economy decides on the principles of carrying out this obligation, and controls the conformity to law of nuclear waste management measures.

Regulatory control

The Radiation and Nuclear Safety Authority (STUK) controls the safety of the handling, storing and disposal of nuclear waste. In order to secure appropriate planning for the disposal of spent nuclear fuel, the authorities have set reporting obligations for nuclear waste producers. STUK reviews the surveys and technical plans aiming at safe disposal of nuclear waste, and provides feedback to Posiva, which is in charge of implementing the disposal.

Estimated cost of disposal

Based on an inventory of 5,500 tU of spent fuel arising from five reactors (two in Loviisa and three in Olkiluoto), a 2009 estimate put the cost of the repository at EUR 3.3 billion. This estimate covers all costs related to final disposal of spent nuclear during the entire 100 year lifetime of the final disposal facility.

Funding of disposal

The State Nuclear Waste Management Fund is a reserve for future costs. The fund was introduced in the Nuclear Energy Act of 1987 and has been operating since 1988. It is not included in the state budget but is an external fund controlled by the Ministry of Employment and the Economy. The funds are included in the cost of the nuclear electricity production. The nuclear power companies pay annual fees to the fund based on the estimated future costs of the nuclear waste management.

Total estimated costs (million Euros) of spent fuel disposal from Olkiluoto and Loviisa (2009)

Construction	710
Operation	2,340
Decommissioning and sealing	280
Total	3,330

Organisation of nuclear waste management in Finland

LICENCES
The Finnish Government
Ministry of Employment and the Economy

REGULATORY CONTROL
Radiation and Nuclear Safety Authority
(STUK)

Implementing organisation for disposal of spent fuel

POSIVA OY

Nuclear Power Companies

TEOLLISUUDEN VOIMA OYJ (TVO)

FORTUM POWER AND HEAT OY

FUNDING OF NUCLEAR WASTE MANAGEMENT
The Finnish State Nuclear Waste Management Fund
Ministry of Employment and the Economy

Posiva Oy

- Company established in 1995
- Ownership: Teollisuuden Voima Oyj 60%, Fortum Power and Heat Oy 40%
- Mission: Safe disposal of spent nuclear fuel of the owners and other tasks of expertise within nuclear waste management
- Gradual change from a R&D company to an implementing organisation
- Own staff more than 90 persons coupled with extensive use of contractors
- Total employment effect of the final disposal over 300 persons

POSIVA

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This brochure tells about safe disposal of spent nuclear fuel into Olkiluoto bedrock. After 30 years of research and development work, our aim is to start the final disposal in 2020.

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