Geologic disposal of spent nuclear fuel in Olkiluoto
The bedrock at Olkiluoto has been investigated by drilling boreholes from the ground surface up to approximately one kilometer in depth. The bedrock structure and rock types are characterised based on the logging of the core samples.
Contents

What is geological disposal?.........4
The journey of uranium from
power plant to final disposal..........6
The multibarrier principle
ensures safety..............................8
Steps of disposal........................10
Disposal responsibilities..............12
All forms of energy production have effects on the environment. The environmental effects of nuclear power are small; the most significant one in Finland is the production of heat in sea areas. A part of the resulting waste is radioactive and it must be isolated from organic nature until its radioactivity has decreased to a harmless level. This isolation is called geologic disposal.

In Finland, each producer of nuclear power-generated electricity is fully responsible for its own nuclear waste management. Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy have been managing their own nuclear waste since the start of their nuclear power plants.

The types of nuclear waste generated in a nuclear power plant are: waste exempted from control, low and intermediate level reactor waste, high level spent fuel, and decommissioning waste. The low and intermediate level waste generated during the operation and outages of the Olkiluoto and Loviisa power plants is stored in the final repository for reactor waste, located at the plant site.

The spent fuel, regarded as high level waste, is currently kept in water pool storage at the plant sites. Later, it will be disposed of in the Olkiluoto bedrock. TVO and Fortum have established Posiva Oy to manage the disposal of spent nuclear fuel produced in their power plants in Finland and associated research and development work. The disposal activities are scheduled to begin in about 2020.

The volume of spent fuel produced by one power plant unit could be fitted, for example, into one 60 m² apartment. The combined amount of spent fuel produced in the power plant units in Olkiluoto and Loviisa is 9,000 tons.
Did you know that...
Research into final disposal has been carried out in Finnish conditions since the 1970s, and the associated research and development work still continues.

1. The bentonite buffer attenuates the radiation level in the disposal tunnel down to the level of natural background radiation.

2. After 40 years, the radiation level inside the disposal hole, on the canister surface, is 59 mSv per hour. After 500 years, it is 0.4 mSv per hour, and after 10,000 years, 0.1 mSv per hour.

3. Two meters of rock attenuates the radiation level down to the level of natural background radiation.

In Finland, the level of background radiation varies between 0.00004 and 0.0003 mSv per hour.
The journey of uranium from power plant to final disposal

There are redundant safety systems in place for every phase of fuel handling, storage, cooling, and transport operations as well as for potential accident situations.

Manufacturing of fuel → Power plant → Interim storage → Encapsulation plant → Final disposal

Manufacturing of fuel

The manufacturing of fuel is a multi-stage process preceded by the mining of uranium ore, enrichment of uranium from the ore, conversion of the concentrate (into uranium hexafluoride), enrichment for the U-235 isotope, and conversion back into powdered uranium dioxide. At the fuel manufacturing plant, the uranium dioxide is compressed into small pellets which are sintered in high temperature and stacked inside zirconium metal fuel rods. The fuel rods are bundled together as assemblies for easier handling. Uranium dioxide is a ceramic with a high melting point of approximately 2,800°C.

Power plant

As the uranium-235 nuclei contained by the fuel split in a fission process inside the reactor, energy is released and the fuel heats up. The heat transfers into water which evaporates into steam which in turn is used to generate electricity with the help of a turbine and a generator.

The fuel remains inside the reactor for approximately five years. During this time, about three percent of the fuel turns into uranium fission products and one percent into plutonium. The rest, 96 percent, is in the same form as when the fuel was inserted into the reactor. Every year, a part of the fuel is replaced. Spent fuel assemblies are cooled down for some years in water pools located in the nuclear power plant unit’s reactor hall. Power plants have redundant safety systems in place for fuel handling, storage, and cooling.
Did you know that...

The radioactivity and heat production of the fuel decreases to approximately one hundredth of the initial value in one year and to less than one thousandth in forty years.

Spent fuel is stored in water pools for several decades before final disposal. After interim storage, the fuel is disposed of at an approximate depth of 420 meters in the Olkiluoto bedrock in copper and cast iron canisters.

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Interim storage

When the spent fuel has sufficiently cooled down in the reactor hall water pools, the assemblies are transferred, in a transport cask, into the water pools of an interim storage facility located in the power plant site. The fuel is cooled down in the cooling pools of the interim storage facility for several decades before it can be finally disposed of. The assemblies placed in the fuel pools are covered by a water layer of approximately eight meters. The water in the pools stops the radiation emitted by the spent fuel and further cools it down.

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Encapsulation plant

In the encapsulation plant, the fuel assemblies are sealed inside copper and cast iron canisters which will shield the fuel from, for example, the effects of groundwater and pressure and prevent the release of radioactive substances into the environment.

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Final disposal

The canisters are placed into deposition holes bored in the bedrock, which are then sealed with compacted but flexible bentonite clay. Finally, the tunnels and related accessways are sealed with clay blocks and pellets.
Geologic disposal is implemented according to the multibarrier principle. This ensures that even if the isolation capability of some of the barriers will be weakened, the other barriers will limit and mitigate the release of radioactive substances from the fuel contained in the canister. Even in a case such as this, the consequences for people and the environment would be insignificant.

Fuel ▶ Shield canister ▶ Bentonite clay ▶ Filling clay ▶ Bedrock

The fuel, uranium dioxide, is compressed into small pellets which are stacked inside zirconium metal fuel rods. The rods are then bundled together as assemblies. The fuel pellet tightly binds long-lived radioactive substances, preventing them from spreading into the environment through dissolution. The fuel pellet is very poorly soluble, even into boiling water, and in the conditions occurring deep in the bedrock, its solubility into bedrock groundwater is particularly poor.

The spent fuel assemblies are encapsulated inside a massive, cast iron, and copper canister. The canister’s cast iron insert provides the required strength and protects the fuel from mechanical stress and pressure. The use of pure copper, a substance known to retain its properties well in the oxygen-free conditions within the bedrock, ensures the tightness of the canister. The canister is placed into a deposition hole bored in the bedrock.
Did you know that...

While the spent fuel is placed hundreds of meters deep inside the bedrock, the combination of isolation measures used in the disposal process is effective enough to stop the radiation emitted by the disposed fuel within a distance of two meters.

Most of the radioactive fission products generated in the fuel are short-lived.

The strength of the canister protects the spent fuel from potential stresses caused by earthquakes or an ice layer up to several kilometers in thickness.

The canister maintains its tightness in the repository conditions for up to millions of years.

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**Bentonite clay**

The canister is isolated from the bedrock with compacted but flexible bentonite clay that contributes to water insulation by preventing groundwater movement the canister’s immediate vicinity, and protects the canister from small rock movements.

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**Filling clay**

The deposition tunnels are backfilled with compacted clay blocks holding the bentonite buffer in place and obstructing the flow of groundwater. After this, the tunnels are carefully sealed by plugging.

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**Bedrock**

The repository will be excavated in an intact, and stable bedrock, and the organic environment is separated by over 400 meters of bedrock. The bedrock will ensure that the conditions around the canisters remain favorable for disposal as well as will retain any released substances and will slow down their migration from the repository.
Steps of disposal

The current situation:
The construction of ONKALO, an underground research facility located in Olkiluoto, began in 2004. The facilities currently completed include personnel and ventilation shafts, access tunnel, and technical rooms. ONKALO enables disposal research in actual conditions. Later, it will form part of the repository.

The situation in early 2020s:
The encapsulation plant, where spent fuel is sealed inside canisters, is completed. The hoist building is also ready. The excavation of the disposal tunnels has started. The first canisters have been disposed of and the first tunnels have been backfilled.
**Did you know that...**

Most of the radioactive fission products generated in the fuel are short-lived. During the first decades after the fuel’s removal from the reactor, the most significant form of radiation is penetrating radiation. Over the long term, after the disposal of the spent fuel, radiation emitted by heavy elements, such as uranium, which is not penetrating in nature, takes over. The radioactive elements remaining at this point are only toxic to humans if ingested or inhaled.

If the canister is not placed safely within bedrock and a person came in close contact with it after 500 years, the radiation dose incurred by that person in one hour would be equivalent to the dose from having four lung x-rays.

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**The situation after approximately 4,000 years:**

The disposal in Olkiluoto has ended in the 2100s. The canisters containing spent fuel are in their places, all tunnels and accessways have been filled, and the whole repository has been closed and sealed. All aboveground buildings have been dismantled and the disposal area has returned to its natural state. Due to the land uplift, Olkiluoto island exists no more; instead, it is now part of the mainland. The materials used to fill the deposition holes and tunnels have largely been soaked with water and swelled into a single mass.

**The situation after 100,000 years:**

The Earth’s climate conditions have changed radically. An ice age is ending, and the ground surface, having pressed down under the weight of ice, is lifting up again. The permafrost occupies the bedrock close to the ground surface. However, at the disposal depth, the underground facilities remain unchanged. The materials used to fill the deposition holes and tunnels have been completely soaked with water and a patina has covered the surfaces of the canisters.
The producers of nuclear power-generated electricity are responsible for the entire fuel chain, including nuclear waste management. The processing of nuclear waste is governed by the Nuclear Energy Act, the Nuclear Energy Decree, and Government Decrees.

Amended in 1994, the Nuclear Energy Act stipulates that all spent nuclear fuel produced in Finland must be disposed of in the Finnish bedrock. The same legislation also prohibits the import, and disposal of, foreign nuclear waste in Finland.

Finnish legislation also stipulates that each operator of nuclear power-generated electricity is responsible for its own nuclear waste management. Teollisuuden Voima Oyj and Fortum Power and Heat Oy have established Posiva Oy to manage the research into, and implementation of, final disposal. The Ministry of Employment and the Economy holds the highest power of control and supervision over nuclear waste management. The Radiation and Nuclear Safety Authority (STUK), an authority operating under the supervision of the Ministry of Social Affairs and Health, supervises the safety of nuclear power generation.

According to decisions-in-principle ratified by the Parliament, spent fuel generated in the Olkiluoto plant units 1–4 and the Loviisa plant units 1 and 2 will be disposed of in a repository to be constructed in Olkiluoto, Eurajoki. According to the target schedule, the start of the disposal shall be possible around the year 2020.

Since the safety is an absolute prerequisite for geologic disposal, the performance of the bedrock, the materials to be used in the disposal process, and the technical solutions are being continually studied. The scenarios of the analyses stretch far into the future, and they consider evolution such as climate change and the formation of a thick glacier and associated bedrock movement. The factors that contribute to safe disposal will be preserved as well as possible during the repository construction phase.

The funds required for the implementation of final disposal are collected in advance by including the estimated costs in the price of electricity. Thanks to this approach, society can rest assured that there will always be enough funds to manage the disposal. A designated fund, independent from the state budget, has been established for the purpose of nuclear waste management.
Did you know that...

When making scoping calculations for determining potential problem situations, the risks are overestimated and pessimistic values used to exaggerated effects.

The targets and emission criteria set by the producers on themselves are more stringent than those set by the authorities.

The repository for spent nuclear fuel is located in Olkiluoto.
Cooperation

Research into disposal technology and safety has been carried out in Finland for several decades.

Posiva works in cooperation with several expert organizations, both Finnish and foreign, and assigns universities, research institutes, and consulting companies to undertake research into nuclear waste management.