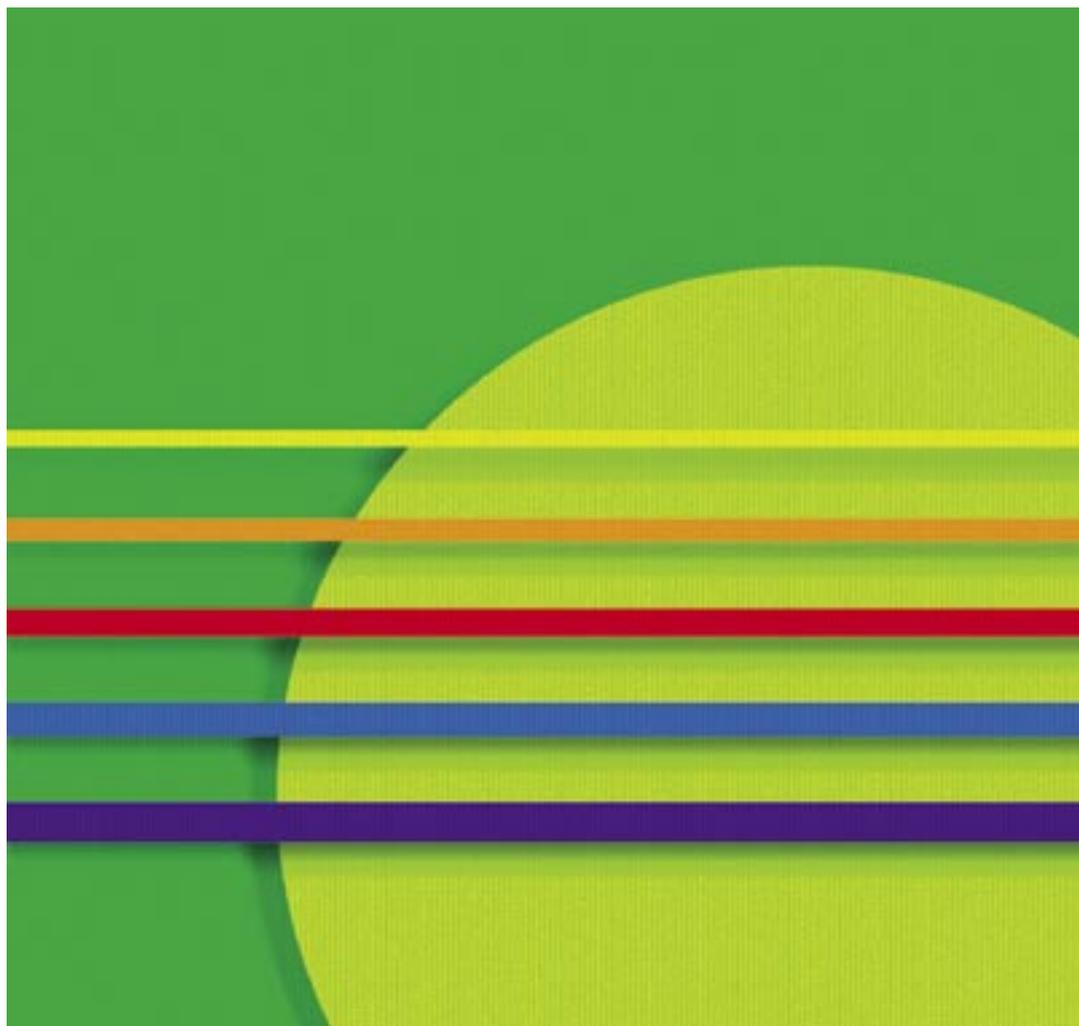


# Nuclear Waste Management in Finland



# Facts about Finland

Independent Republic since 1917  
 Member State of the European Union since 1995

Capital:	Helsinki
Neighbouring countries:	Estonia, Norway, Russia and Sweden
Area:	338 000 km <sup>2</sup>
Population:	5.28 million
Population density:	15.5 persons per km <sup>2</sup>
GDP per capita at market prices (2006):	EUR 31 886
Monetary unit:	euro (EUR)
Total primary energy consumption (2006):	32.6 Mtoe
Total electricity consumption (2006):	90.0 TWh
Electricity consumption per capita:	17 054 kWh
Share of nuclear energy in Finland (2006):	24.4 % of total electricity consumption 28.0 % of domestic electricity production

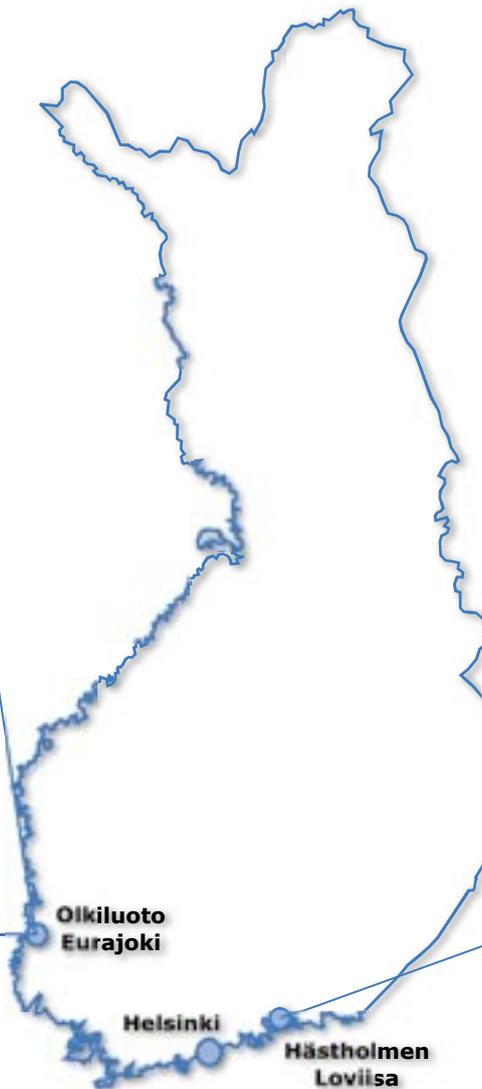


## OLKILUOTO

**Operator:** Teollisuuden Voima Oy  
**Type:** BWR  
**Power:** 2 x 860 MWe  
**Operation started:** 1979 and 1982  
**Production:** 15.9% of total energy consumption in Finland  
**Load factor:** 95.4% (2006)



**Under construction:**  
**Olkiluoto 3**  
**Type:** EPR  
**Power:** 1600 MWe  
**Operation scheduled to start:** 2011



## LOVIISA

**Operator:** Fortum  
**Type:** PWR  
**Power:** 2 x 488 MWe  
**Operation started:** 1977 and 1981  
**Production:** ca. 8.6% of total energy consumption in Finland  
**Load factor:** 91.0 % (2006)

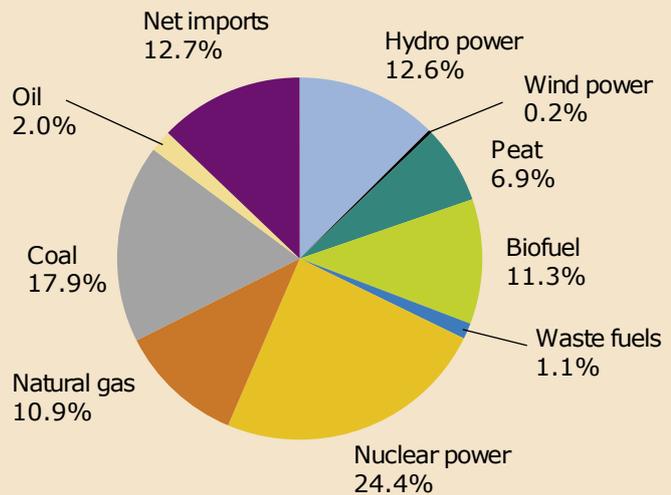
## Nuclear energy in Finland

**The Finnish energy mix has always been diverse. Finland's geographical location, climate and natural resources have limited the energy options available. The Finnish standard of living and welfare have been gradually built on a foundation of strong industrial development.**

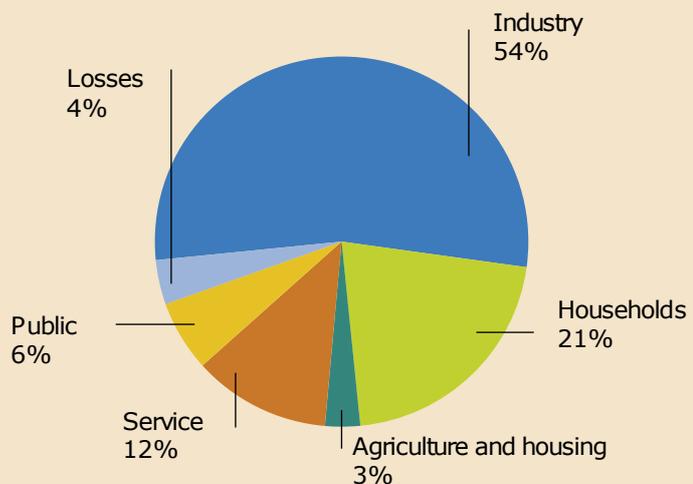
The four nuclear power plant units in Finland were put into operation between 1977-1982. Throughout its history in Finland, nuclear power has provided a solid base load in power generation. About 26-27 per cent of the annual electricity supply is generated at the four Finnish nuclear power units. Two of them are operated by Fortum in Loviisa and two by Teollisuuden Voima Oy (TVO) in Olkiluoto in the municipality of Eurajoki. In addition, TVO has a third unit under construction in Olkiluoto, expected to be in operation in 2011.

The planning and preparation for nuclear power started in Finland in the 1960s and 1970s. Loviisa and Olkiluoto were chosen as the plant sites on the basis of thorough evaluations. Local environmental conditions, fauna, and flora were carefully mapped and recorded to allow subsequent evaluation of the impacts of the nuclear power plants (NPPs). Samples were also taken from local forests, farms, fields and residents in order to form a baseline of the conditions, levels of emissions, and radiation for research that continues even today.

### Electricity supply by energy source 2006 90.0 TWh



### Electricity consumption 2006 90.0 TWh



# General principles in nuclear waste management

“Nuclear waste generated in connection with or as a result of the use of nuclear energy in Finland shall be handled, stored and permanently disposed of in Finland.”

Nuclear Energy Act 990/1987:  
Management of nuclear waste generated in Finland (1420/1994)

manent disposal of nuclear waste originating from other countries is strictly forbidden.

### Polluter pays

The nuclear power companies are responsible for all the costs related to nuclear waste management, including decommissioning.

The power companies bearing the waste management obligations have established a joint company, Posiva Oy, to execute the necessary research and implementation of spent fuel disposal.

Preparations for nuclear waste management started in the early 1970s. The scope and the schedule were defined in the Government’s decision in principle in 1983.

In 2001, the Parliament ratified a

decision in principle about the final disposal of spent nuclear fuel. A year earlier Olkiluoto had been chosen as the site of the facility to be built in the bedrock.

The handling, storing and per-

## Nuclear waste can be classified into three different categories:

### Operating Waste

Operating waste consists of low- (LLW) and intermediate-level (ILW) waste. LLW includes protective plastic sheets, tools, protective clothing and towels used in service work. ILW consists of the ion-exchange resin used to purify the process water. Olkiluoto generates 150-200 m<sup>3</sup> of operating waste and Loviisa 100-150 m<sup>3</sup> each year.

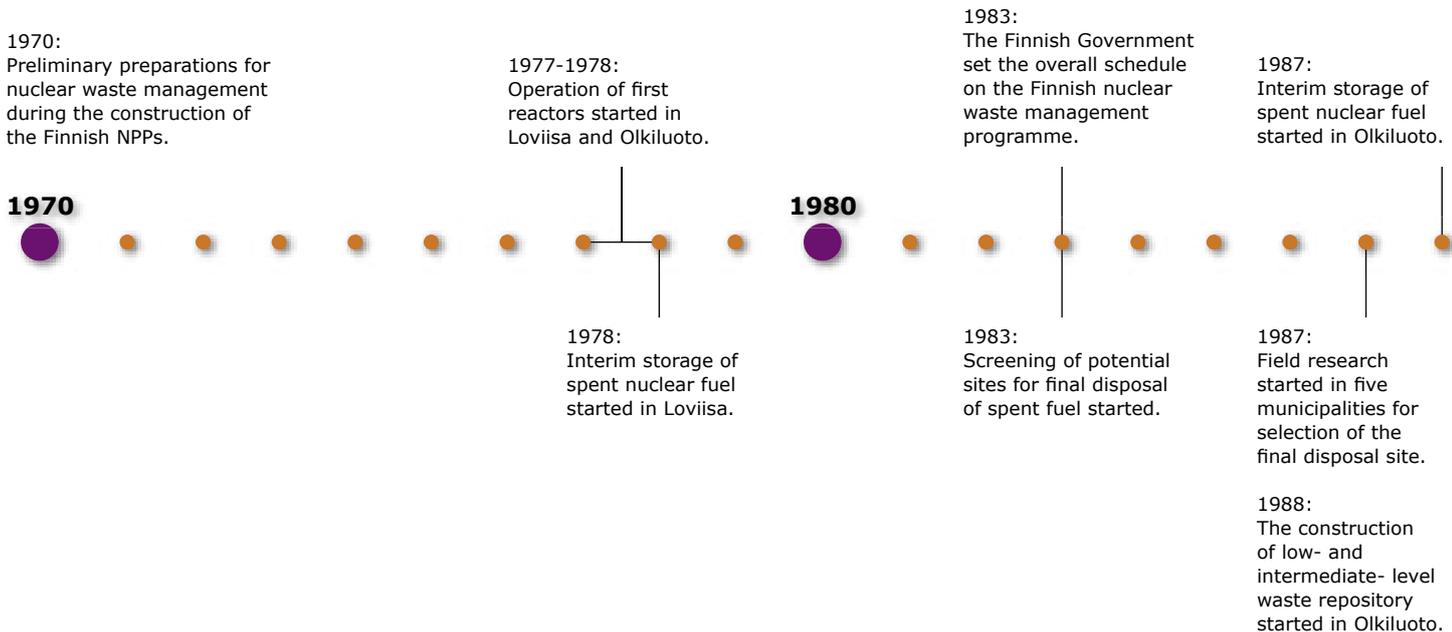
### High-Level Waste

**(including spent nuclear fuel)**  
The four nuclear power plant units in Finland produce a total of some 70 tonnes of spent fuel a year. In all the reactors a quarter of the fuel rod assemblies are replaced each year. Spent nuclear fuel can be reprocessed but that is not the case in Finland. Spent fuel is allowed to cool in a water pool for a few years, after which it is transferred to interim storage facilities on the plant site.

### Decommissioning Waste

Decommissioning refers to nuclear waste management actions taken after a nuclear power plant has been closed. Some of the structures in a nuclear power plant become radioactive over time. One of the most important structures in this respect is the reactor pressure vessel. Final disposal of decommissioning waste is planned to take place on the nuclear power plant sites of Loviisa and Olkiluoto.

## Timeline



# National Nuclear Waste Management Fund

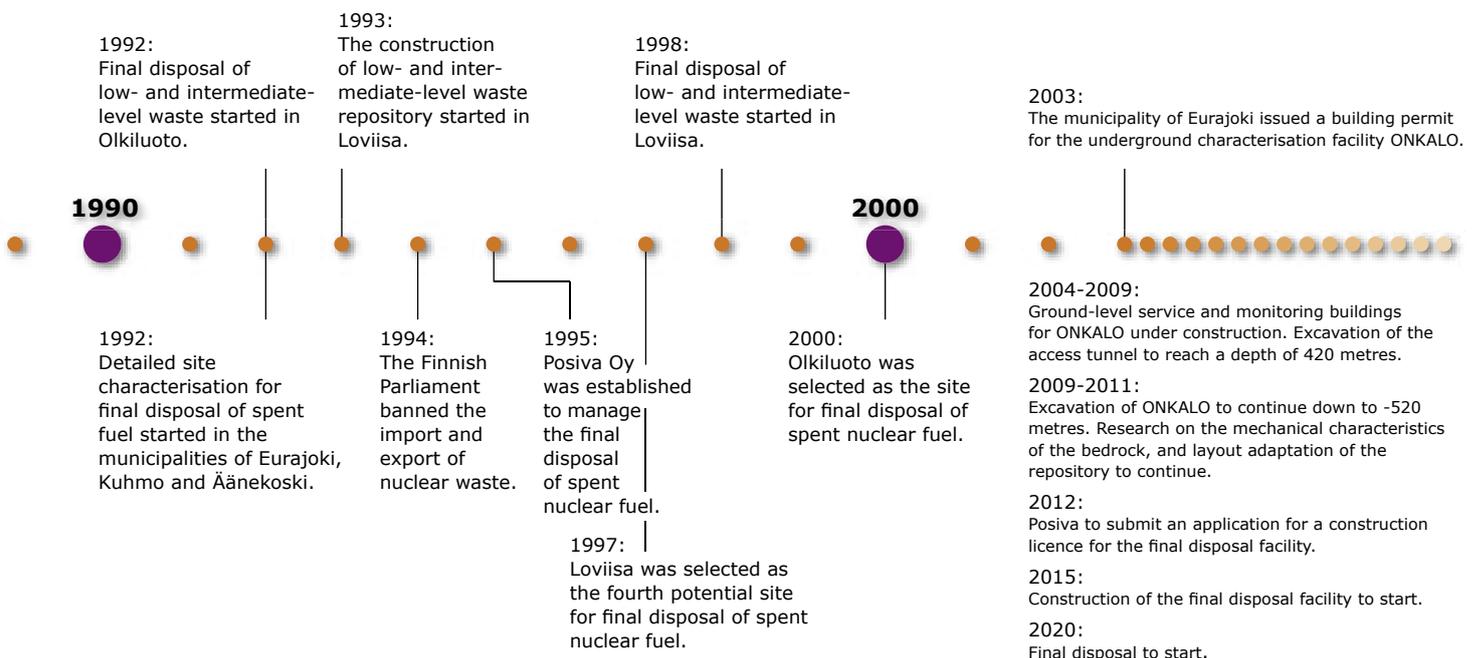
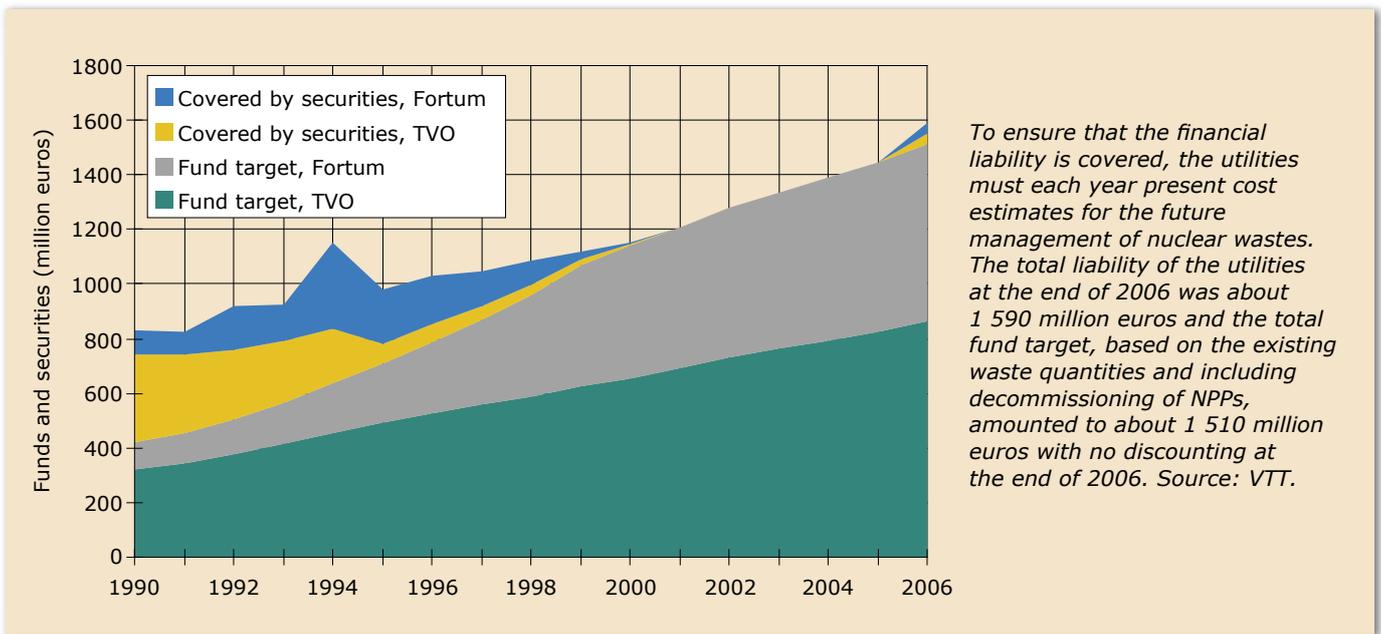
The power companies that produce nuclear energy are responsible for all the costs related to the planning and implementation of nuclear waste management. The costs of waste management have from the very beginning been taken into account in the price of electricity produced by the nuclear power plants.

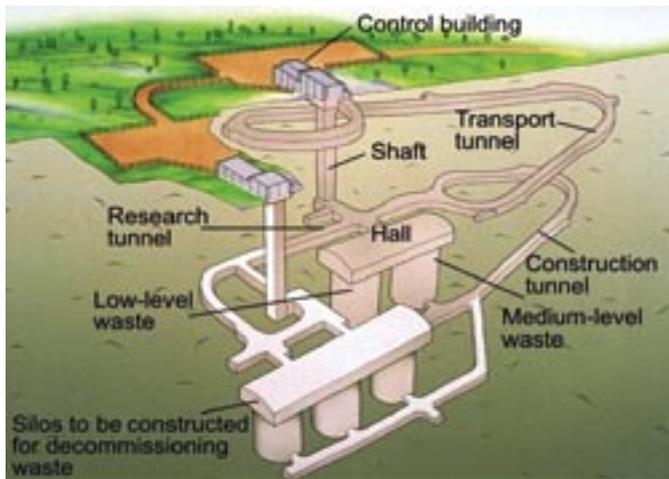
Each year the funds for all remaining waste management activities are deposited in the independent National Nuclear Waste Management Fund. The Fund is controlled and administered by the Ministry of Trade and Industry.

An estimate of the assessed liability is made annually. It is based

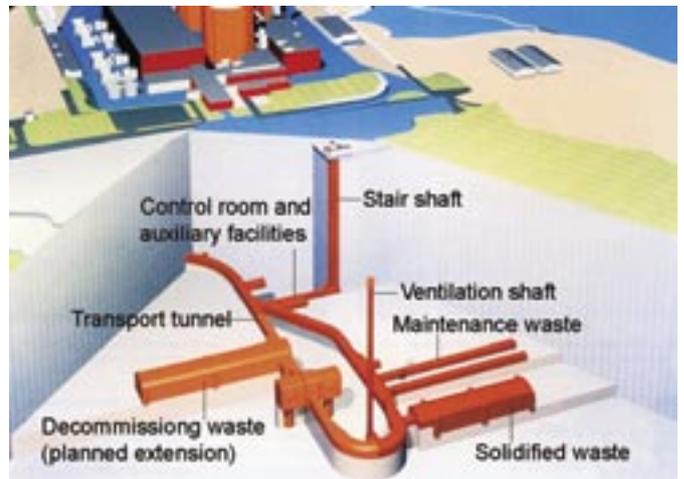
on basic nuclear waste management decisions and the best knowledge available at the time to enable implementation as necessary and in due time.

The uncertainty of available information about prices and costs is to a reasonable extent taken into account when raising the assessed liability.





The final disposal repository for operating waste in Olkiluoto was put into operation in 1992.



In Loviisa, final disposal of operating waste started in 1998.

## Final disposal of operating waste started in the 1990s

Operating waste is waste generated during the operation and maintenance of the nuclear power plant. Low-level waste includes, for example, protective plastic sheets, protective clothing, tools and sheets used in maintenance work. Intermediate-level waste consists of liquids, slurries and the ion-exchange resin used to purify process water, for example.

The power companies plan all work carefully and try to avoid generating any unnecessary decontamination or waste. All materials and people are monitored by the radiation protection personnel when leaving the controlled area. All waste is sorted and classified according to the activity level.

The Radiation and Nuclear Safety Authority has issued strict guidelines for the processing, storage and handling of different types of operating waste. Low-level waste is compressed with a hydraulic press to half its original volume and packed in barrels. Liquid radioactive waste is dried and mixed with a solid agent, such as bitumen, and then cemented in barrels.

The final disposal of operating waste started in Olkiluoto in 1992. The repository is located some 100

metres underground. In Loviisa, final disposal of operating waste started in 1998 in the repository built ca. 110 metres underground.

Both the repositories are excavated in the bedrock. The waste containers are transported to the repository by a special shielded vehicle. All containers are appropriately marked and recorded.

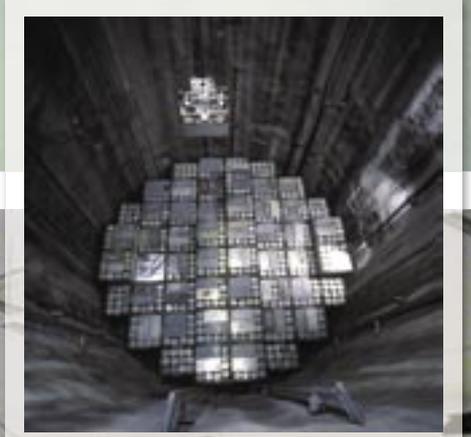
Loviisa produces 100-150 m<sup>3</sup> of operating waste annually, and Olkiluoto 150-200 m<sup>3</sup>. The repositories will accommodate all the operating waste generated during the lifetime of the power plants. The plant site repositories have been designed to serve also as final disposal sites for decommissioning waste once the power plants reach the end of their lifetime.



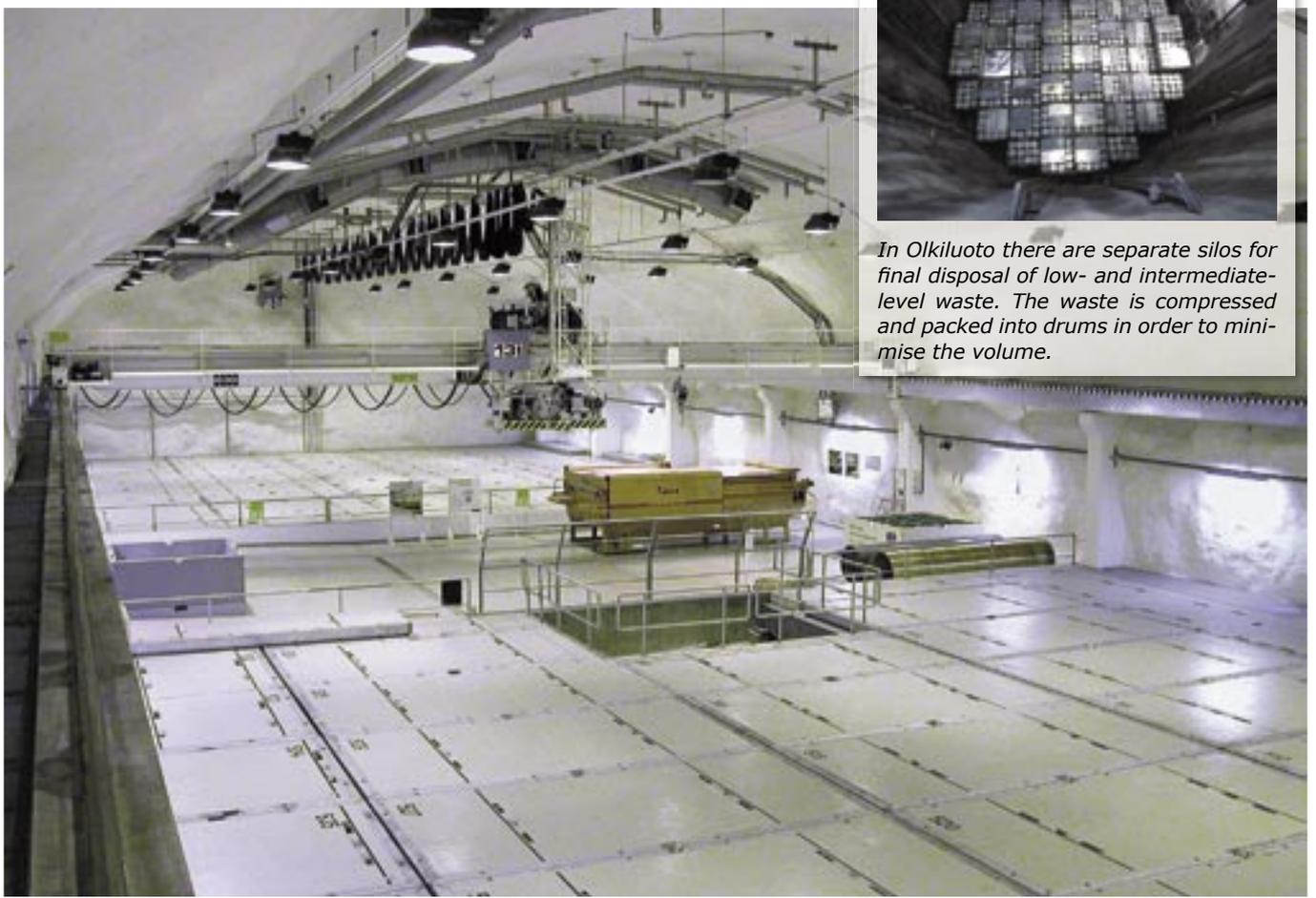
All waste is classified by radioactivity as 'clean', low-level and intermediate-level radioactive waste, decommissioning waste and highly radioactive spent fuel. Waste containing no radioactive substances is classified as 'clean'. It is recycled and the portion that cannot be recovered is taken to TVO's own landfill. Low-level and intermediate-level waste is packed into containers in the power plants.



Low- and intermediate-level waste is transported to the final repository in a specially designed vehicle. The vehicle and the load are checked before they are taken into the repository. The unloading is carried out by remote controlled crane.



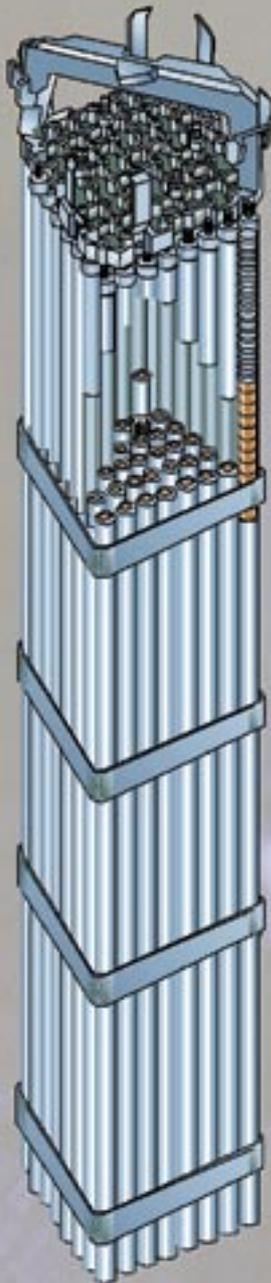
In Olkiluoto there are separate silos for final disposal of low- and intermediate-level waste. The waste is compressed and packed into drums in order to minimise the volume.



The final disposal repository for low- and intermediate-level waste in Olkiluoto



*Uranium pellets.*

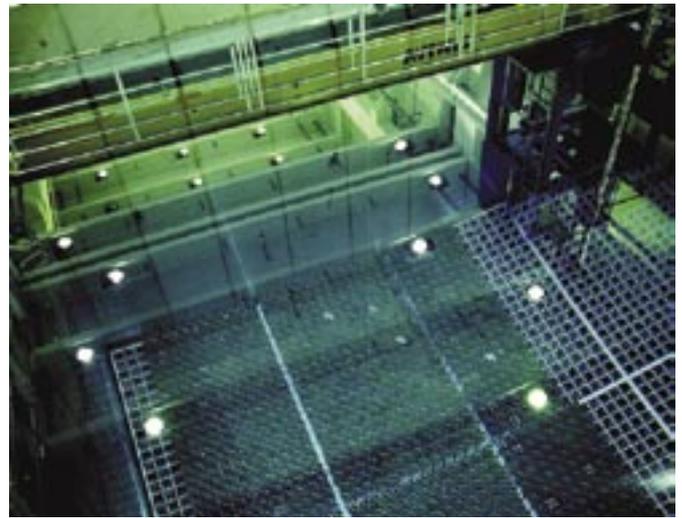


*The fuel assembly used at Olkiluoto 1 and 2 plant units.*

*About one third of the fuel in Loviisa and a quarter of the fuel load in the Olkiluoto reactor units are replaced annually with fresh fuel. The picture is taken during the reloading of Loviisa power plant. The blue glow is Cerenkov radiation.*



When the spent fuel is taken out of the reactor it cools down in the reactor hall for few years. After that the spent fuel is transported to the interim storage located on the plant site.



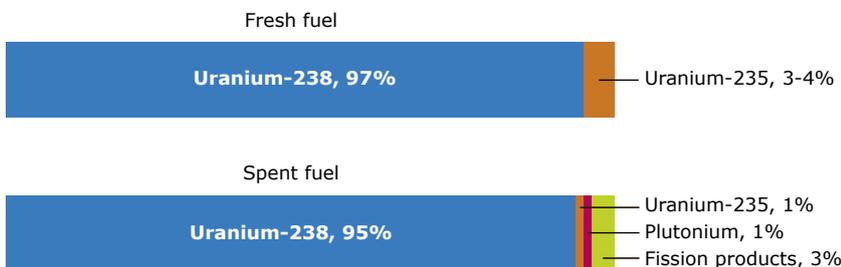
Spent fuel is stored and cooled underwater in the interim storage. The photo is from Olkiluoto.

## Spent nuclear fuel awaits final disposal underwater

About one third of the fuel in Loviisa and a quarter of the fuel load in the Olkiluoto reactor units are replaced annually with fresh fuel. The four Finnish nuclear units produce some 70 tonnes of spent nuclear fuel each year. The spent fuel is removed from the reactor during the annual outage. The fuel assemblies are placed

underwater in a cooling pool located nearby in the reactor facility.

After a few years, the assemblies are lifted from the cooling pools and transported to the spent fuel repository for interim storage. The assemblies are stored underwater for further cooling. The interim storage is located in the plant area.



Fresh fuel consists of two isotopes of uranium, fissionable U-235 and stable U-238. In spent fuel the fission has transformed some of the fissionable uranium into transuranic elements and fission products. Transuranic elements have an atomic mass greater than uranium. Transuranic elements are, for example, plutonium-239 and plutonium-241. Fission products, for example cesium-137, have an atomic mass less than that of uranium. Both transuranic elements and fission products are usually radioactive.



A transport cask for spent nuclear fuel in Olkiluoto.

## Encapsulation starts the final disposal process

The Finnish final disposal concept has been developed by Posiva in close cooperation with the Swedish company SKB (Svensk Kärnbränslehantering AB). Both countries plan to implement final disposal of spent nuclear fuel in the bedrock.

After the spent fuel assemblies have been removed from the reactor, they are allowed to cool down for at least 20 years before the final disposal process can proceed. After a few decades the radioactivity level and heat generation in the fuel are reduced to less than a thousandth part of the original level.

When the fuel assemblies have cooled down enough, they are transported to an encapsulation plant. The plant is located at ground level above the actual repository. The encapsulation plant is equipped with a system that protects the outside world from radiological consequences should anything extraordinary take place during the encapsulation process.

During encapsulation the spent fuel assemblies are sealed into canisters. The canister consists of copper overpack and cast iron insert. The canisters are closed by welding and transported to the final disposal tunnels. The tunnels are located at a depth of ca. 400 metres below the surface.

### Multiple barriers isolate spent fuel from organic nature

Nuclear waste is isolated from organic nature and from people by multiple barriers. Both natural and engineered barriers are used. Several hundreds of metres of bedrock on top of the spent fuel protects the waste against possible future ice ages. The bedrock also creates stable and predictable conditions for the canisters in the repository.

The canisters are transported to the disposal tunnels and embedded in drilled holes. After the canister has been placed in the hole, it is backfilled with bentonite clay. Ben-

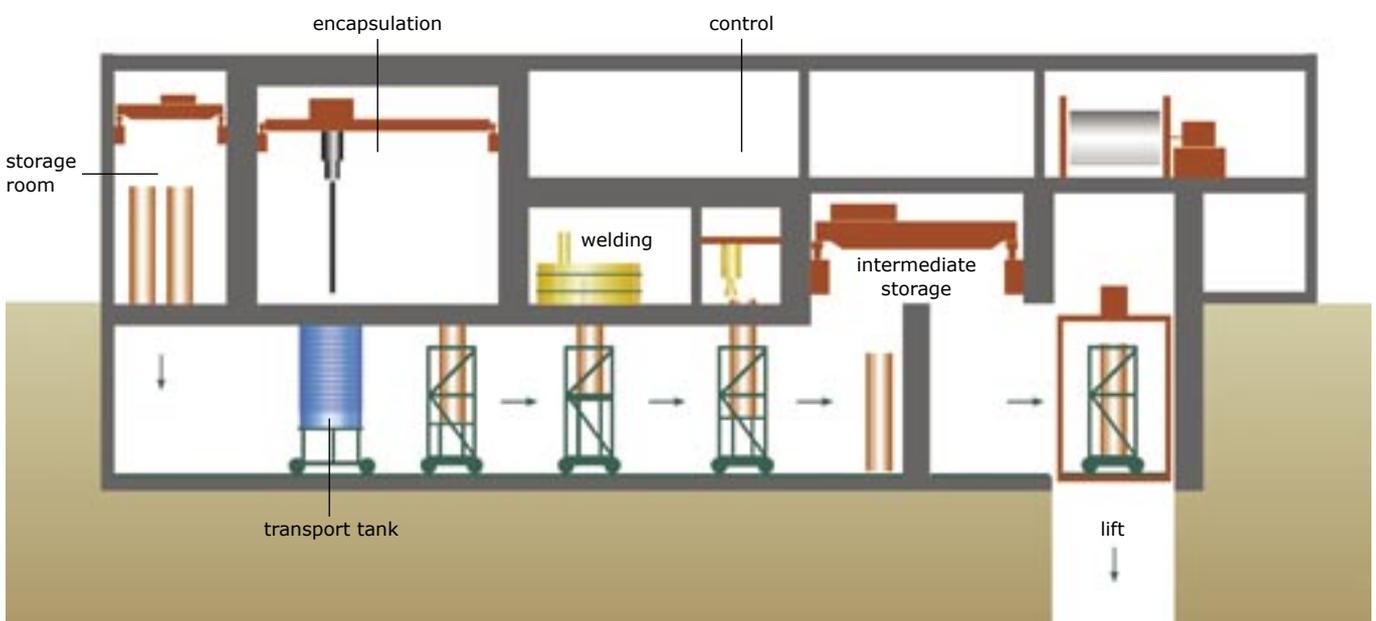
tonite absorbs water very efficiently and isolates the canister from any water and protects it against minor bedrock movements.

The current four nuclear units are estimated to generate around 3500 tonnes of spent uranium fuel. With the fifth unit taken into account, the total amount of spent fuel equals 5500 tonnes of uranium.

Once the final disposal of spent nuclear fuel is completed in about 2120, the encapsulation plant will be decommissioned. All the tunnels will be backfilled and sealed. The facility needs no monitoring after it has been closed.

The spent fuel can be retrieved from the repository at any stage of the final disposal process. Even after the facility is closed, the spent fuel can be retrieved, albeit not without considerable costs.

### Encapsulation plant for spent nuclear fuel





## Final disposal canisters

The fuel rod assemblies used at Olkiluoto and Loviisa differ in shape and length but they can be packed in copper-nodular iron canisters of similar construction.

The copper canister tightly encloses nodular cast iron insert, protecting it from corrosive influence of groundwater.

Extensive experimental and theoretical analyses have shown that even in unfavourable conditions the 5-cm thick copper case used in the canisters would take hundreds of thousands of years to corrode. The internal canister made of nodular cast iron is sufficiently strong to withstand the mechanical stress acting on the canister in the bedrock.

The canisters will be emplaced in the repository tunnels spaced a few metres from each other and then surrounded by bentonite clay,

which expands considerably when it absorbs water. The clay will not only prevent direct water flow to the sur-

face of each canister, but also protect the canister against minor bedrock movements.

### **Loviisa 1 and 2**

- Height 3.6 m
- Mass 16.1 t (empty)
- 12 spent fuel assemblies per canister

### **Olkiluoto 1 and 2**

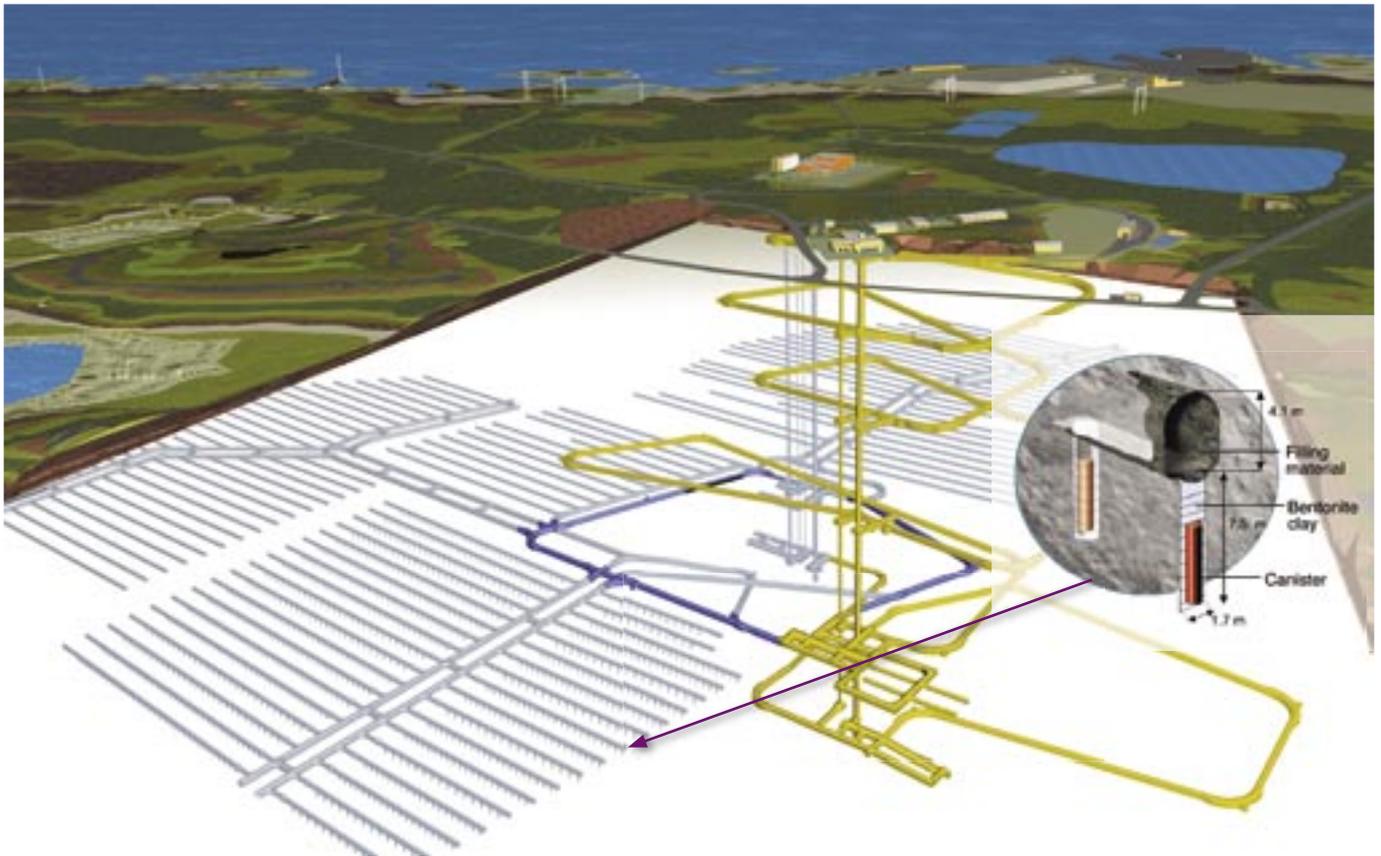
- Height 4.8 m
- Mass 20.7 t (empty)
- 12 spent fuel assemblies per canister

### **Olkiluoto 3**

- Height 5.2 m
- Mass 26.0 t (empty)
- 4 spent fuel assemblies per canister



LO1-2 OL1-2 OL3



Posiva is currently excavating an underground characterisation facility referred to as ONKALO. The project started in 2004. ONKALO will provide "on site" information of the rock conditions for final disposal research. The main investigation level will be located ca 400 m underground.

## Underground characterisation facility ONKALO



Drilling of a canister hole.

The underground research facility being built for rock characterisation for the final disposal of spent nuclear fuel is known as ONKALO.

After the Government's favourable policy decision in 2001, Posiva focused further investigations on Olkiluoto and began preparations for the construction of an underground characterisation facility, ONKALO. The municipality of Eurajoki granted a building permit for ONKALO in August 2003.

Numerous deep test holes were drilled in the investigation area at Olkiluoto to obtain further information for planning ONKALO. The construction of ONKALO started in 2004 and the characterisation of the bedrock is scheduled to be completed

by 2011.

The project seeks to obtain exact information about the bedrock on the site of final disposal for the purpose of planning the final disposal repository and assessing its safety and to test final disposal technology in actual deep underground conditions. The construction of ONKALO down to main investigation level is expected to cost EUR 70 million.

After the ONKALO stage, or in the 2010s, start-up will begin on building the encapsulation plant and final repository. These stages require a separate licensing process. Additionally, the plant requires a favourable safety evaluation from the Radiation and Nuclear Safety Authority (STUK) before it can start operating.

## Research findings are combined into models and future scenarios

Safety analyses study the reliability of the final disposal system and take into account various future scenarios and courses of events as well as the consequences to humans and/or nature should one or more of the safety barriers fail and radioactive material is released from the final disposal repository.

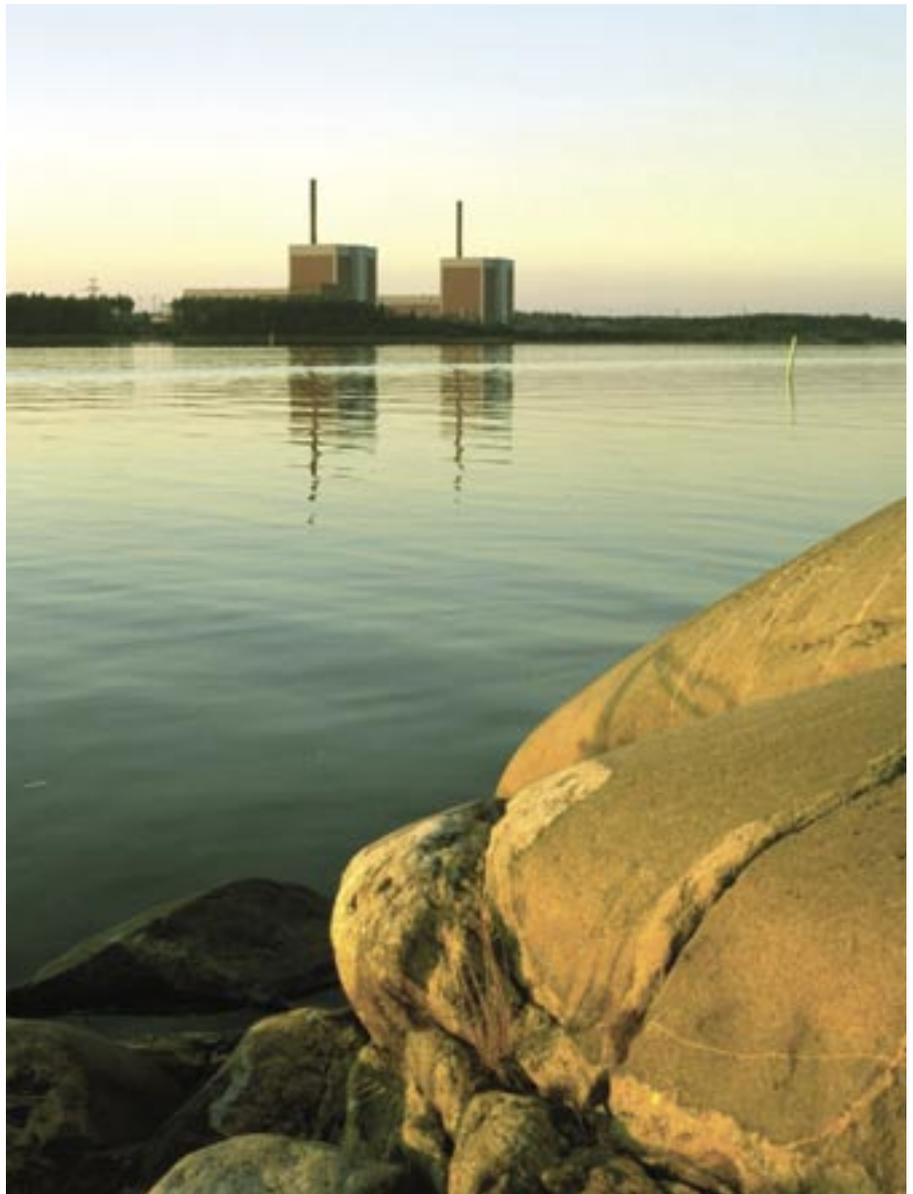
Analyses combine and apply observations, tests and theoretical knowledge from different branches of science. Risks and consequences resulting from uncertainties and unknowns are overestimated. Analysis methods are assessed in open scientific debate and in information exchange between experts.

The bedrock area suitable for final disposal must be geologically stable and have no major fractures. It must also be ordinary bedrock so that future generations have no need to excavate rock at the disposal site.

Geological investigations have studied the fracturing and water conductivity of the bedrock and groundwater flow. Since groundwater only flows along fractures in the rock, investigations have focused on fractures and water conductivity. Exact locationing of crush structures and fractures makes it possible to predict potential movements of the rock areas. Rock stress can be relieved through the crush structures without any significant transformations taking place in the rock inside the zones.

The findings of numerous investigations have been combined into models, the most significant of which are the bedrock model and the groundwater model. These are used to estimate the groundwater flow at the research site and to investigate the significance of this flow for the safety of final disposal.

Research and development work also includes the planning of nuclear waste transport and the encapsula-



tion plant, the positioning of the required rock facility and the structural development of the final disposal container. Additionally, both Finnish and foreign laboratories have studied how the heat of the spent fuel and the groundwater affect the encapsulation materials and the bentonite clay used to isolate the canisters.

A considerable amount of Posiva's research, development and technical engineering work is carried out in joint international projects involving two or more partners.

The company is collaborating

particularly with SKB (Svensk Kärnbränslehantering AB) of Sweden to develop encapsulation and final disposal technology, and in this respect work is focused on the Äspö Hard Rock Laboratory and the canister laboratory at Oskarshamn.

Joint projects involve horizontal emplacement technology of the final disposal canisters (KBS-3H) and development of backfilling technology. Äspö is also home to field tests that model the function of the bedrock as a natural release barrier to evaluate longterm safety.

## The role of authorities in nuclear waste management

The authorities in charge of nuclear issues are the Ministry of Trade and Industry and the Radiation and Nuclear Safety Authority STUK. They are responsible for the principles that govern nuclear waste management, as well as for safety criteria and ensuring compliance with legislation.

The operation and maintenance of the Finnish NPPs are strictly monitored by the Radiation and Nuclear Safety Authority STUK. Annual outages are planned and executed in a systematic manner as processes that continue for years. No changes are allowed in the process or in the practices without STUK's approval.

STUK also monitors the operation and the environment inside and outside the NPPs. Samples are taken on a regular basis from the surrounding forests, fields, sea area, air, plants, animals, people and products such as milk, and analysed for any radioactive emissions.

### Policymakers involved in final disposal of spent fuel through Government's decisions

By virtue of the Nuclear Energy Act, the construction project of a final disposal facility requires three separate decisions from the Government of Finland.

In 2000 Posiva applied for a decision in principle on the final disposal of spent nuclear fuel. The Finnish Government made the decision in 2001. The decision also required

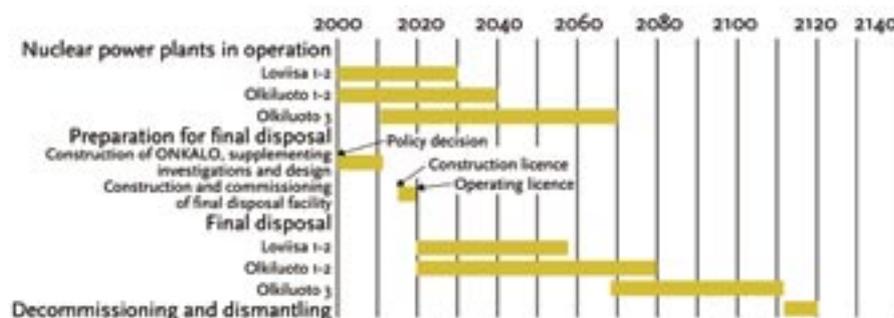
ratification by the Parliament, stating that the project would serve the overall good of the Finnish society.

The decision was based on statements obtained from the municipality of Eurajoki and from the Radiation and Nuclear Safety Authority STUK.

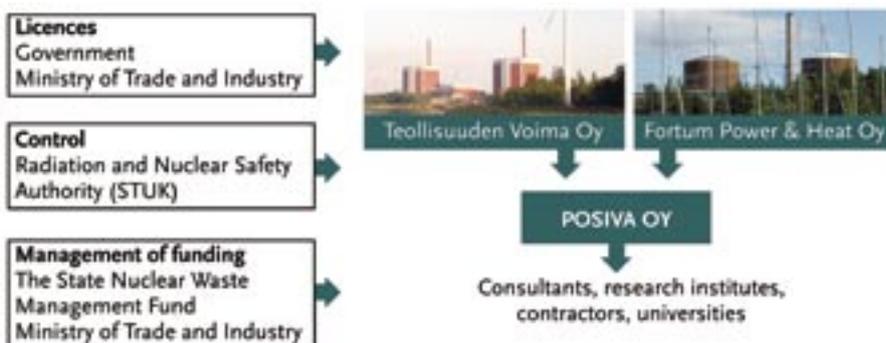
The statutory environmental impact assessment (EIA) was also carried out for the project.

The Government will also need to grant a separate construction licence and an operating licence for the facility.

### Total schedule of final disposal



### Nuclear waste management organisation





## Fortum

Fortum is a leading energy company in the Nordic countries and the other parts of the Baltic Rim. Fortum's activities cover the generation, distribution and sale of electricity and heat, the operation and maintenance of power plants as well as energy-related services.

Fortum Power and Heat Oy and Fortum Nuclear Services Oy are engaged in nuclear energy activities. In addition to the Loviisa nuclear power plant, Fortum owns minority shares of the Olkiluoto nuclear power plant and of the Swedish Forsmark and Oskarshamn nuclear power plants. Fortum Corporation was listed on the Helsinki Exchanges in December 1998. The State owns 50.8 % of the shares. In 2006, the consolidated net sales of the Fortum Group amounted to about EUR 4491 million, electricity sales totalled 60.2 TWh in the Nordic countries and 29.6 TWh in Finland, and the company employed about 8100 people.



## Teollisuuden Voima Oy

Teollisuuden Voima Oy produces electricity for its shareholders on a production cost basis at the Olkiluoto nuclear power plant in Eurajoki and at the Meri-Pori coal-fired power plant. TVO's principal task is to secure economical, safe and environmentally-friendly electricity generation for its shareholders at the present plant units of Olkiluoto. The company's objective is to keep the plant units as-good-as-new condition and to further develop the personnel's expertise.

TVO has six shareholder companies. The company has three share series: 1) Existing units (OL1 & 2), 2) Olkiluoto 3, and 3) Meripori coal-fired plant. TVO is part of the PVO Group, the parent company of which is Pohjolan Voima Oy. In 2006, the company's net sales amounted to EUR 227 million and it sold 14.2 TWh of electricity. TVO has about 748 permanent employees.



## Posiva Oy

Posiva is an expert organisation established by TVO and Fortum to take care of their spent nuclear fuel. Posiva is responsible for the research related to the final disposal of spent fuel and later also for the construction and operation of the final disposal facility. In addition, Posiva's line of business includes other expert services in the field of nuclear waste management, provided for the two owner companies and other customers.

Posiva employs over 70 experts in the field of nuclear waste management. Posiva utilises not only Finnish expertise of the field but also contracts international research institutes. Research connected with nuclear waste management is carried out in universities, research institutes and consulting companies representing expertise in different fields. Posiva is owned by TVO (60%) and by Fortum Power and Heat Oy (40%). The annual turnover was approximately EUR 43 million in 2006. Posiva's office is located at Olkiluoto, in Eurajoki.



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