OPERATING LICENCE APPLICATION

SPENT NUCLEAR FUEL ENCAPSULATION PLANT AND DISPOSAL FACILITY

Posiva

Maailman johtava loppusijoittaja

CONTACT INFORMATION
Posiva Oy Olkiluoto
27160 Eurajoki
Phone: +358 2 8372 31
Business ID: 1029258-8
posiva.fi

Photo: Posiva Oy

TO THE GOVERNMENT OF FINLAND

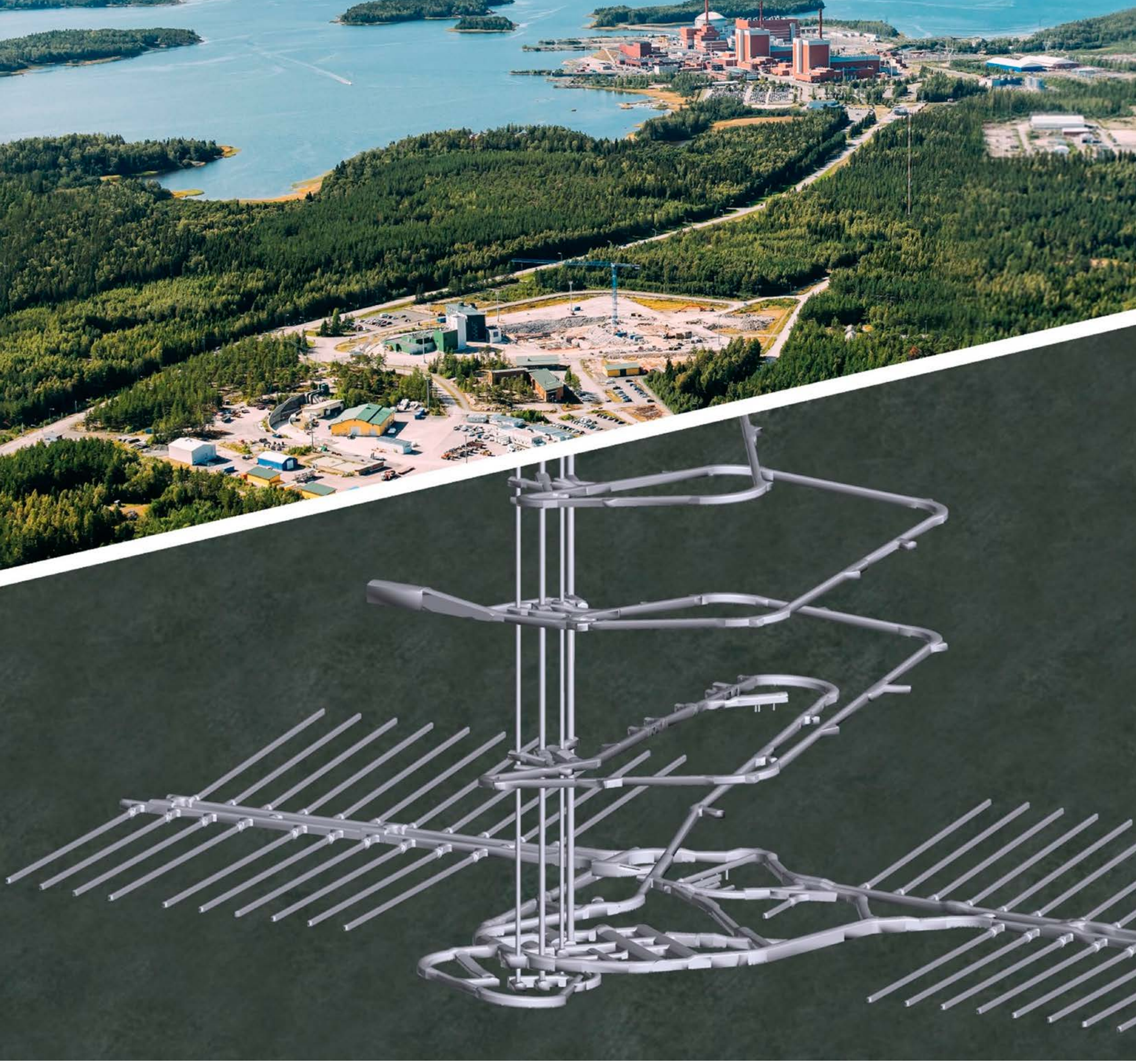
OPERATING LICENCE APPLICATION FOR
A SPENT NUCLEAR FUEL ENCAPSULATION PLANT
AND DISPOSAL FACILITY

APPLICANT

The applicant's trade name is Posiva Oy (hereinafter referred to as the "Applicant") and it is domiciled in Eurajoki.

The Applicant's shareholders are Teollisuuden Voima Oyj (hereinafter referred to as "TVO") (60%) and Fortum Power and Heat Oy (hereinafter referred to as "Fortum") (40%). The Applicant owns 100% of the shares in its subsidiary, Posiva Solutions Oy; together, this company and the Applicant form the Posiva Group. The Applicant's field of business, pursuant to its articles of association, is the management – including final disposal – of spent nuclear fuel and other high-level nuclear waste from TVO's nuclear power plant units Olkiluoto 1, Olkiluoto 2 and Olkiluoto 3, located at Olkiluoto, and Fortum's nuclear power plant units Loviisa 1 and Loviisa 2, located in Loviisa, as well as from any new nuclear power plant units constructed in Finland by the Applicant's shareholders in order to meet the licensee's waste management obligation referred to in the Nuclear Energy Act in a safe and economical manner, and the research and development work required by the above.

More detailed information on the Applicant is available in Appendices 1, 2, 7, 8 and 9 to this application.



The image presents an animation of ONKALO (disposal repository) below the encapsulation plant area. Together, they form the world's first final disposal solution for spent nuclear fuel. Nuclear waste management is an important part of the acceptability of nuclear power and sustainability; for its part, it secures basic electricity production in Finland and promotes the implementation of the national energy and climate strategy.

APPLICATION

Via this application, the Applicant is applying for a licence, as referred to in Section 20 of the Nuclear Energy Act (990/1987), to operate the encapsulation plant and disposal facility for spent nuclear fuel, constructed on the island of Olkiluoto in the municipality of Eurajoki in accordance with the terms of the construction licence (TEM/2955/08.05.01/2012, 12 November 2015), from March 2024 until the end of 2070.

During the entire course of the final disposal activities, approximately 6,500 tonnes of uranium (hereinafter, "tU") of spent nuclear fuel, corresponding to approximately 3,300 final disposal canisters, will be placed in final disposal. According to the current plans, the final disposal activities will continue until the 2120s, at which time all the spent nuclear fuel produced by the nuclear power plant units of Posiva's shareholders will have been placed in final disposal.

During the operating licence period applied for by the Applicant, until the end of 2070, it is estimated that approximately 4,000 tU of spent nuclear fuel will be placed in final disposal; at this time, the spent nuclear fuel from the Olkiluoto 1 and 2 plant units (hereinafter, "OL1" and "OL2") and the Loviisa 1 and 2 plant units ("LO1" and "LO2") will have been placed in final disposal. Following this, the Applicant will be applying for a new operating licence for the final disposal of any remaining spent nuclear fuel from the aforementioned plant units and, in particular, the spent nuclear fuel from the Olkiluoto 3 plant unit (hereinafter, "OL3").

The Applicant is requesting a licence referred to in section 20 of the Nuclear Energy Act as follows:

- The licensee may possess, process, store and place in final disposal spent nuclear fuel generated from the operation of TVO's nuclear power plants at Olkiluoto and Fortum's nuclear power plants in Loviisa up to an amount of 6,500 tU.
- The licensee may possess, produce, process, store and place in final disposal low and intermediate level nuclear facility waste generated from the operation and decommissioning of the encapsulation plant and disposal facility and the nuclear facilities of Posiva's shareholders in a manner where the total volume of nuclear facility waste will not exceed 3,000 m3 under any circumstances.
- The licensee may possess, produce, process, store and place in final disposal radioactive waste.
- The licensee may possess, produce, process, use, store and dispose of other nuclear material required for the operation of the encapsulation plant and disposal facility as follows: material already existing in the nuclear material balance area or at the plant site and other nuclear material, provided that materials requiring an import permit have been granted an import permit in accordance with the Nuclear Energy Act.

The transport of spent nuclear fuel from the nuclear power plant units in Loviisa to the encapsulation plant constitutes use of nuclear energy pursuant to the Nuclear Energy Act and is, thereby, only possible under a licence applied for separately pursuant to chapter 8 of the Nuclear Energy Decree (161/1988) and granted by the Radiation and Nuclear Safety Authority (hereinafter, "STUK"). The Applicant will be applying for the necessary licences for transport according to the Nuclear Energy Decree as the final disposal of spent nuclear fuel from the nuclear power plant units in Loviisa begins; according to current plans, this will take place in the 2040s. The transfer of spent nuclear fuel from the plant units at Olkiluoto to the encapsulation plant will take place as an internal transfer within the nuclear power plant area.

The Applicant's final disposal activities also make provisions for the final disposal of other intermediate-level nuclear facility waste and radioactive waste, such as the reactor internals of nuclear power plant units, if their final disposal inside the Applicant's nuclear facility is safer or more purposeful than using the Applicant's shareholders' own final disposal facilities for low and intermediate level nuclear waste (hereinafter referred to as the "VLJ repository").

The Applicant proposes that the conditions of the operating licence state that the decommissioning plan update pursuant to section 7 g of the Nuclear Energy Act shall be submitted to the Ministry of Economic Affairs and Employment (hereinafter, "TEM") for approval in connection with the periodic safety assessment pursuant to section 7 e of the Nuclear Energy Act, that, is every 15 years. The justification presented for this is that the operating life of the encapsulation plant and disposal facility will be approximately one hundred years, and the six-year interval proposed in the Nuclear Energy Act is not purposeful over such a long time span.

The Applicant requests that the Government, by virtue of section 122 of the Administrative Judicial Procedure Act (808/2019), decide, when granting the licence, to enforce the decision despite any possible appeals, as the enforcement of the decision cannot be postponed due to a public interest. In order to guarantee safe and timely nuclear waste management, it is in line with the general interest of society to begin the final disposal of spent nuclear fuel immediately after an operating licence has been received, in spite of any possible appeal.

OBJECT OF THE APPLICATION

The object of the application is a plant complex that consists of an encapsulation plant constructed above ground, where the spent nuclear fuel is enclosed in final disposal canisters, and an underground disposal facility in which the spent nuclear fuel will be placed in final disposal inside deposition tunnels constructed at a depth of more than 400 metres. A separate space for the low and intermediate level waste generated during the final disposal activities will be later constructed in connection with the driving tunnel of the disposal repository. From the ground surface to the disposal repository, there is a driving tunnel and vertical shafts for ventilation, personnel traffic and canister transfers. The disposal facility also has other technical rooms and auxiliary rooms required for the final disposal activities.

At the encapsulation plant, the spent nuclear fuel is packed and enclosed, by means of remote control, into final disposal canisters manufactured from copper and cast iron, after which the integrity of the canisters is ensured. Following this, the filled final disposal canisters will be transported by means of a canister lift into the disposal facility for interim storage at a depth of more than 400 metres. From the interim storage of the disposal facility, the final disposal canisters are transferred to the deposition tunnels where they are placed in deposition holes, after which the deposition holes are covered with buffer bentonite clay. Finally, the deposition tunnels are filled with a bentonite clay material and the mouth of the tunnel is closed with a massive steel-reinforced concrete plug.

Pursuant to the Nuclear Energy Act, the starting point for the construction and operation planning of the encapsulation plant and disposal facility has been to create a safe and requirements-compliant plant complex that will not cause harm to people, the environment or property. During construction, the design basis of the plant complex has been continuously assessed in accordance with the best available knowledge. The plan is to operate the Applicant's nuclear facilities over a time cycle where spent nuclear fuel is encapsulated into final disposal canisters to wait in interim storage, after which the canisters will be placed in final disposal inside deposition holes during campaigns that last a few months at a time. This enables the efficient and safe operation of the encapsulation plant and disposal facility. The encapsulation plant and disposal facility have been designed to be safe to operate. The most important documents guiding the operation of the facility have been approved by STUK, and STUK supervises the operation of the facilities according to its own inspection programme.

Once the disposal facility has been finally closed, its safety has been ensured by means of a safety case assessed over a very long time interval (long-term safety) that has been submitted to STUK for approval as part of the operating licence application documentation. The safety case is also available on the Posiva website. Based on the results of the long-term safety assessment, final disposal is safe and under no conditions will radioactivity be released into the environment in any amount that would affect the health of humans or biological organisms. A summary of the long-term safety assessment can be found in Appendix 5 to this application.

The disposal facility will be constructed and closed in stages as the final disposal progresses, until the 2120s. STUK will supervise and approve the construction of the parts of the disposal facility constructed during operation, so that the facilities being constructed meet the safety requirements set for them. Once the disposal facility is finally closed, STUK will approve it and the control of the disposal facility is transferred to the state. The location of the encapsulation plant and disposal facility and the final disposal area are described in Appendix 3 to this application.

Small volumes of radioactive nuclear facility waste are generated from the processing of spent nuclear fuel; such waste is processed and placed in interim storage in the interim storage facilities for nuclear facility waste inside the Olkiluoto nuclear power plant area, pursuant to the licences concerning the interim storage

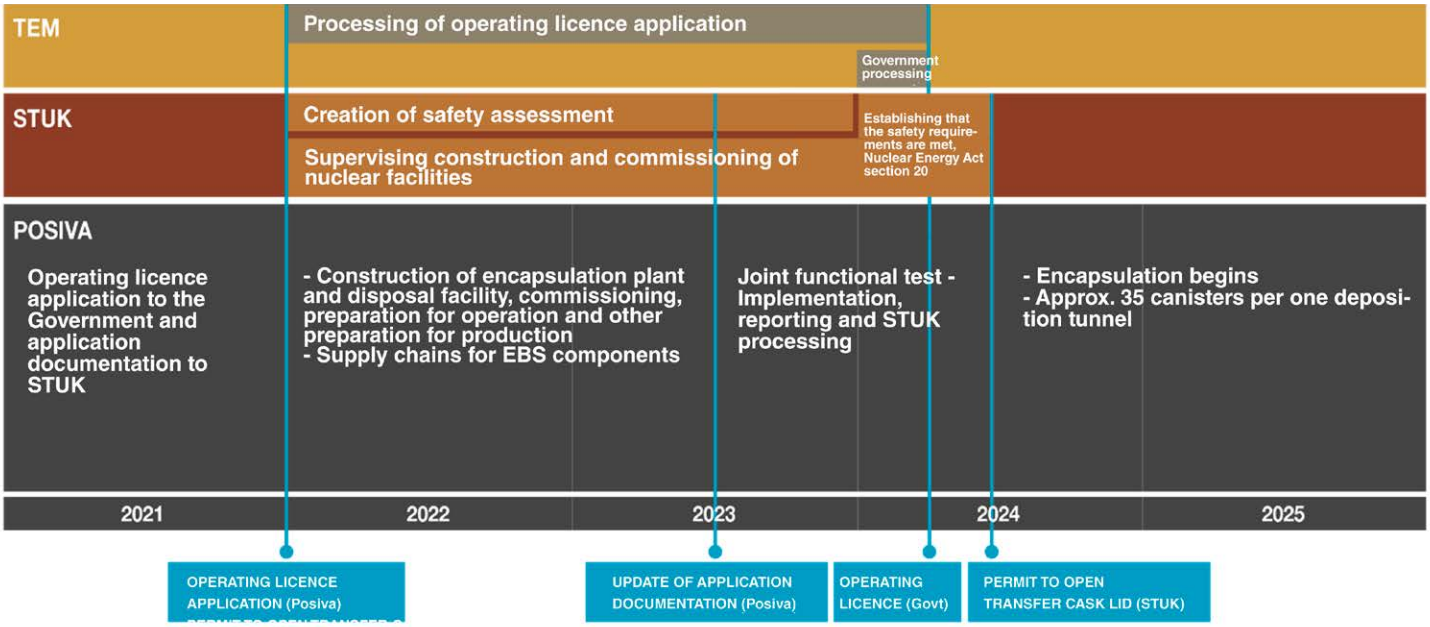


Figure 1. Target schedules for the operating licence of the encapsulation plant and disposal facility. The operating licence application is submitted to the Government (VN), but it is processed by the Ministry of Economic Affairs and Employment (TEM). The Radiation and Nuclear Safety Authority (STUK) prepares a safety assessment of the application documentation, and it must be favourable.

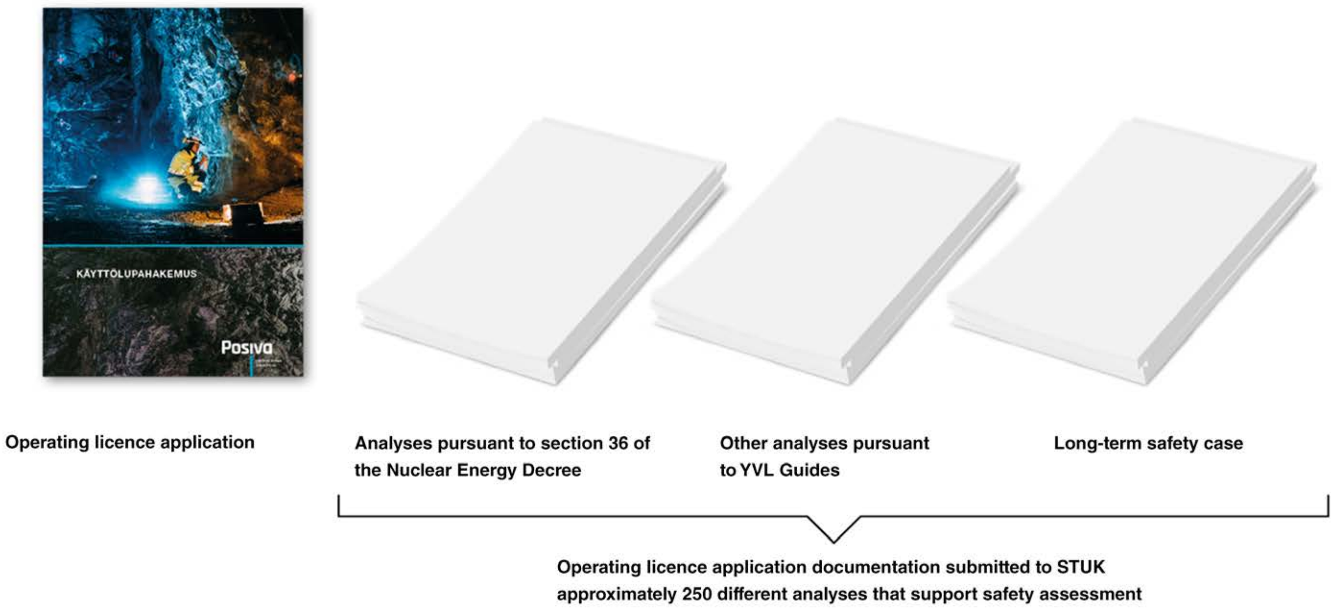


Figure 2. Structure of the operating licence application and the documentation submitted for the purpose of assessing safety. The documentation submitted to STUK contains, among other things, descriptions of the systems and structures of the nuclear facilities and analyses regarding the assurance of operational safety, radiation safety and long-term safety.

facilities. The principles of Posiva's nuclear waste management have been approved by TEM and, pursuant to them, Posiva and TVO sign an agreement on the transfer of the waste management obligation before final disposal activities are started. Following the transfer, TVO will handle the processing, storage and final disposal arrangements for very low, low and intermediate level nuclear facility waste in accordance with TVO's waste management processes.

TVO will place the nuclear facility waste generated by the Applicant's activities in final disposal inside the VLJ repository or the near-surface final disposal facility at Olkiluoto. Since the operation of TVO's nuclear power plant units will end before the end of the Applicant's final disposal activities, provisions for in-house nuclear facility waste management have been made in the design of the encapsulation plant and disposal facility. A space for nuclear facility waste has been designed in connection with the disposal facility at a depth of some 180 metres along the driving tunnel; it will be constructed and commissioned if necessary, in case the VLJ repository at Olkiluoto is closed before Posiva's disposal facility, for example. Provisions will be made for the final disposal of other decommissioning waste and operating waste from Posiva's shareholders, as well as small amounts of other radioactive waste, inside the space for nuclear facility waste, if necessary. In this case, a separate assessment is required concerning long-term safety.

During the operating licence period under this application, spent nuclear fuel from the OL1 and OL2 as well as the LO1 and LO2 plant units will be placed in final disposal. The operating period for the encapsulation plant and disposal facility is approximately one hundred years, in which case the planned operating time would end in approximately 2120. On 13 August 2020, Fortum initiated an EIA procedure for the continued operation or decommissioning of the Loviisa 1 and Loviisa 2 plant units and, in its plans, Posiva has prepared for the final disposal of spent nuclear fuel in both options. The Applicant has made preparations for the final disposal of Fortum's spent nuclear fuel in both options.

However, final disposal activities for spent nuclear fuel may continue for longer than planned, as new nuclear power plant units may be commissioned or the operating period for the current units may be extended. The long operating period emphasises the need to research and develop the safety and efficiency of final disposal activities throughout the operation, in line with the guiding principles of section 7 a of the Nuclear Energy Act. Appendix 5 describes the functional principles of the encapsulation plant and disposal facility and their safety characteristics and explains the development of the final disposal solution.

The Applicant is planning to perform periodic safety assessments on the encapsulation plant and disposal facility during the operating licence term, in accordance with the Nuclear Energy Act, at 15-year intervals from the granting of the operating licence and until the end of the operating licence. The contents of the assessment are defined on the basis of applicable international and national recommendations and practices as well as the regulations and requirements issued by STUK.

The Applicant has enclosed with this application the analyses referred to in section 34 of the Nuclear Energy Decree and the analyses defined in the conditions of the construction licence (12 Nov 2015, TEM/2955/08.05.01/2012). The Applicant has also submitted to STUK the analyses for the assessment of safety pursuant to Section 36 of the Nuclear Energy Decree and the YVL Guides.

RATIONALE FOR THE APPLICATION

BACKGROUND OF THE APPLICATION AND PREVIOUS DECISIONS AND LICENCES

Decisions-in-principle

The Government has granted to the Applicant three decisions-in-principle concerning the construction of the encapsulation plant and disposal facility on 21 December 2000, 17 January 2002 and 6 May 2010, which the Parliament has decided to retain in force on 18 May 2001, 24 May 2002 and 1 July 2010, respectively. The decision-in-principle made in 2000 concerns the spent nuclear fuel generated from the operation of the four operating nuclear power plant units in Finland, the total amount of uranium being a maximum of approximately 4,000 tU. The decision-in-principle made in 2002 on the construction of the disposal facility with an extension concerns spent nuclear fuel from TVO's OL3 nuclear power plant unit, now in its commissioning stage, with an amount of at most 2,500 tU. In total, 6,500 tU may be placed in final disposal in accordance with the decisions-in-principle, corresponding to approximately 3,300 final disposal canisters filled with spent nuclear fuel. The decision-in-principle concerning the Olkiluoto 4 plant unit expired, as TVO did not submit a construction licence application for it. Therefore, Posiva's decision-in-principle for the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit also expired.

Construction licence

On 12 November 2015, the Applicant was granted a construction licence (TEM/2955/08.05.01/2012) for the construction of an encapsulation plant and disposal facility. Pursuant to the terms of the licence, in December 2016, Posiva started construction according to the construction licence. By virtue of the construction licence, the licensee is allowed to construct

1.1 an encapsulation plant and disposal facility for spent nuclear fuel, the total amount of which shall correspond to no more than 6,500 tonnes of uranium.

1.2 disposal repository facilities for the low and intermediate level operation and decommissioning waste from the encapsulation plant and disposal facility. Disposal repository facilities may be constructed to an extent where the rooms may contain a maximum of 1,500 m^3 of low and intermediate level waste.

1.3 the structures and auxiliary facilities required for the operation of the encapsulation plant and disposal facility and the disposal repository.

1.4 the basic solution (vertical deposition holes) or a variation thereof (horizontal disposal tunnels).

2. Together with the operating licence application, the licensee shall submit an updated analysis of the environmental impacts of the plant complex.

3. Together with the operating licence application, the licensee shall submit an updated analysis of the retrievability of the spent nuclear fuel.

4. Together with the operating licence application, the licensee shall submit an updated analysis of the risks related to the transport of spent nuclear fuel.

5. Together with the operating licence application, the licensee shall submit an analysis of the changes that have been introduced into the project.

The Applicant has constructed the encapsulation plant and disposal facility pursuant to the terms of the construction licence, and it will construct the disposal repositories and the structures and auxiliary facilities required for the operation during the term of the operating licence.

The analyses required in the conditions of the construction licence (items 2–5 above) are included in Appendices 10–13 to this application. Therefore, the Applicant states that the terms of the construction licence have been met.

Notices

The Applicant has notified the European Commission of an investment project related to final disposal activities in connection with the processing of the construction licence application. The basic technical data for the encapsulation plant and disposal facility were first reported during the construction licence application stage, and changes to them have been reported as necessary. Posiva will compile the notice required for the assessment of the environmental impacts of the project in 2022.

SITE

The encapsulation plant and disposal facility are located in the municipality of Eurajoki, in an area governed by a local detailed plan of the Olkiluoto final disposal area, which the Applicant has control over. The encapsulation plant is located at the centre of Olkiluoto island, some 2 kilometres east of the location of the nuclear power plant units. The disposal facility is located at a depth of more than 400 metres in the Olkiluoto bedrock. The surface area required for the underground facility section is approximately 150 hectares for the final disposal of 6,500 tU of fuel. The total length of the underground tunnels is approximately 35 km after all of the spent nuclear fuel has been placed in final disposal. However, tunnels will be closed over the course of the final disposal operations as soon as they become full.

More detailed analyses regarding the site and land use planning are presented in Appendix 3 to this application.

INTENDED PURPOSE

The encapsulation plant and disposal facility are used for the encapsulation and final disposal of spent nuclear fuel from the nuclear power plant units of Posiva's shareholders. In addition, the encapsulation plant has space reservations for the future construction, if necessary, of systems and spaces for the processing, storage and final disposal into the Olkiluoto bedrock of nuclear facility waste and other radioactive waste.

The Applicant's nuclear facility consists of two interconnected nuclear facilities, that is, the encapsulation plant and disposal facility. At the encapsulation plant, spent nuclear fuel is encapsulated inside final disposal canisters, after which the canisters are transferred into the disposal facility at a depth of slightly above 400 metres. At the disposal facility, they are placed in final disposal inside tunnels constructed for this purpose, and the tunnels are filled and finally closed with a plug. If necessary, a separate disposal repository for the low and intermediate level operation and decommissioning waste generated from the processing of the spent nuclear fuel will be constructed in connection with the disposal facility during its operation.

More detailed analyses concerning the operation of the Applicant's nuclear facility are presented in Appendices 4 and 5 to this application.

OPERATING TIME AND FINAL DISPOSAL ACTIVITIES

The duration of the final disposal activities is estimated at approximately 100 years, which means that operation is planned to last until the 2120s. Pursuant to the construction licence, the amount of nuclear fuel processed at the encapsulation plant and placed in the disposal facility shall be equivalent to at most 6,500 tU, which corresponds to approximately 3,300 final disposal canisters. Slightly over 40% of the canisters will contain fuel from the OL1 and OL2 plant units, slightly below 40% will contain fuel from the OL3 plant unit, and approximately one fourth will contain spent fuel from the Loviisa plant units. If the decision is made to continue the operation of the Loviisa plant units, the proportion of canisters containing their fuel will increase. The volume of radioactive operation and decommissioning waste generated at the encapsulation plant is estimated to be approximately 1,500 m^3 and its activity is estimated at approximately 600 GBq.

The Applicant has chosen KBS-3V (vertical deposition holes) as its basic solution for the final disposal. Its alternative, KBS-3H (horizontal deposition tunnels) is not being actively developed at the moment. Considering the long duration of the final disposal activities, the Applicant may reassess the KBS-3H option during the operation pursuant to the guiding principles in section 7 a of the Nuclear Energy Act. KBS is the abbreviation

Figure 3. For the final disposal, Posiva has selected the KBS-3V method developed together with SKB, which is responsible for the final disposal of spent nuclear fuel in Sweden. This is a principle for final disposal first developed in Sweden which is based on the multi-barrier principle.

for "Kärnbränslesäkerhet" and the number 3 is the version number of the final disposal concept. The letter V, in turn, refers to the vertical deposition of final disposal canisters.

The spent nuclear fuel is received at the Applicant's above-ground encapsulation plant, where the fuel elements are packed and sealed in final disposal canisters. The encapsulated spent nuclear fuel is placed in final disposal in the disposal facility that is constructed in connection with the encapsulation plant, deep inside the bedrock. The disposal facility comprises the disposal repositories for nuclear fuel and a separate final disposal hall for low and intermediate level operating and decommissioning waste that will be constructed if necessary. The underground facilities include the driving tunnel, vertical shafts, technical rooms, vehicle connections, central tunnels and disposal repositories. The disposal repositories comprise the deposition tunnels and the deposition holes drilled in their floors where the canisters are placed. In addition to spent nuclear fuel, small volumes of other intermediate-level nuclear waste, including parts that have become radioactive inside the reactor, will be placed in final disposal if necessary.

According to current plans, final disposal will take place at an annual rate of at most 60 final disposal canisters. The design capacity of the encapsulation plant is approximately 100 canisters per year. During the first years, approximately 30–40 canisters per year will be placed in final disposal. Final disposal activities will be performed in campaigns, during which final disposal canisters are first packed to wait in interim storage at the encapsulation plant and disposal facility, after which the canisters will be placed in final disposal inside one of the deposition tunnels and the tunnel will be closed with bentonite clay backfill and a plug. More detailed analyses concerning the encapsulation plant and disposal facility and its technical operating principles are presented in Appendices 4 and 5 to this application.

PRECONDITIONS FOR GRANTING A LICENCE (NUCLEAR ENERGY ACT, SECTION 20)

THE OPERATION OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY IS SAFE

In Finland, TEM is responsible for the high-level management and supervision of the nuclear energy industry. The supervising authority for the safety of nuclear energy use is STUK. The Applicant's operation meets the requirements of the national authorities. The Applicant also adheres to international agreements as regards nuclear safeguards and nuclear liability, for example.

The encapsulation plant and disposal facility and their operation meet the requirements concerning safety in force in Finland pursuant to the Nuclear Energy Act and Decree, the general principles of which are included in the regulations issued by STUK and, in more detail, in the nuclear safety guidelines (YVL Guides) and emergency preparedness guidelines (VAL Guides) issued by STUK. In addition, the principles and guidelines published by certain other countries and the International Atomic Energy Agency (IAEA) have been taken into account. The design and operation of the encapsulation plant and disposal facility also take into account, for example, the requirements in the radiation legislation and other applicable requirements in the Finnish legislation. The Applicant is continuously monitoring and assessing how the various legislative requirements are being met within the operation. An analysis of the applied safety principles and an assessment of compliance with them is presented in Appendix 5 to this application.

The safety of final disposal has been ensured. The disposal facility is located at a depth of more than 400 metres, below the encapsulation plant. The disposal facility will be built inside bedrock, whose conditions and suitability for final disposal have been researched for nearly 40 years. The disposal facility and method of disposal have been demonstrated to be safe for hundreds of thousands of years, during which time the radioactivity in the spent nuclear fuel will have decreased to a level occurring in natural uranium ore. The disposal facility will be expanded and closed throughout the operation, so at the end of the operation, approximately 35 kilometres of the disposal facility will have been excavated and closed underground.

The safety of the final disposal of spent nuclear fuel has been assessed hundreds of thousands of years into the future; this is referred to as the long-term safety assessment. Long-term safety has been assessed at the decision-in-principle stage, construction licence stage and, presently, at the operating licence stage. These assessments have determined that final disposal is safe even over long periods of time. If the integrity of the final disposal canisters is lost, according to the least favourable and most unlikely future evolutions, the radiation dose incurred by humans and animals will be approximately one tenth of the regulatory limits and one hundredth of the dose that humans receive annually from background radiation and other radiation sources. An analysis of the actions taken in order to limit the environmental load caused by the nuclear facility is included as Appendix 6 to the application, and a summary of the long-term safety assessment is presented in Appendix 5 and Appendix 10.

The Applicant is actively involved in various international forums concerning the nuclear energy industry and the final disposal of nuclear waste. Furthermore, the Applicant's operations are subject to international peer reviews, and any possible areas for improvement arising from them are taken into account in the Applicant's operations.

The safety of the Applicant's employees working at the encapsulation plant and disposal facility has been appropriately accounted for. The goal of the Applicant's industrial safety activities is to promote health and industrial safety pursuant to the "zero accident" approach. The Applicant maintains a good work atmosphere and working conditions. No form of harassment or bullying in the workplace is allowed in the Applicant's work community. Everyone is responsible for ensuring their own safety and the safety of others. Industrial safety is considered in all activities.

The radiation safety of employees working at Olkiluoto is ensured by meeting the requirements of the Radiation Act (859/2018), the Government Decree on ionising radiation (1034/2018) and the decisions, regulations and regulatory guidelines issued on their basis, and by adhering to the Applicant's own, more specific radiation protection instructions.

The Applicant is implementing an action programme that aims to keep the individual and collective doses of the employees as low as reasonably achievable (ALARA). This ALARA programme combines the most important goals concerning the radiation protection of the workers and the reduction of their doses. The nuclear safeguards and the security and emergency preparedness arrangements of the encapsulation plant and disposal facility have been appropriately set up and they meet the national and international requirements set for them.

THE OPERATION OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY IS SAFE THROUGHOUT THE COURSE OF THE FINAL DISPOSAL ACTIVITIES

ENVIRONMENTAL PROTECTION AND THE SAFETY OF THE POPULATION HAVE BEEN CONSIDERED IN THE OPERATION OF THE PLANT AND FACILITY

The direct and indirect effects of the encapsulation plant and disposal facility on humans, nature and the built environment have been assessed in several environmental impact assessment programmes in accordance with the Act on Environmental Impact Assessment Procedure (468/1994). The coordinating authority has determined that the presented assessment reports are sufficient and found that they meet the requirements of the legislation and that the processing is appropriate. The Applicant has in place a documented and certified activity management system that meets the requirements of the international SFS-EN ISO 14001 standard in terms of environmental aspects. One purpose of the activity management system is to ensure that the management of environmental aspects is guided and systematic.

In general, the impacts of the encapsulation plant and disposal facility's operation on humans and the environment include land use, the underground excavation of the disposal facility, landscape impacts, possible radioactive releases, impacts on water systems, traffic impacts, traffic safety, impacts on the economy and employment, and noise. Of these, mainly the banking of excavation waste and any possible radioactive releases may cause safety impacts beyond those that can be expected from other industrial operations. According to the decision by the Regional State Administrative Agency for Southern Finland (ESAVI-0000426-05.14.00-2011, 19 Jan 2011), the encapsulation plant and disposal facility do not require an environmental permit.

The updated *"Analysis of the environmental impacts of the plant complex"* is included in Appendix 10 to this application, and the updated *"Analysis of the actions taken in order to limit the environmental load caused by the nuclear facility"* is presented in Appendix 6.

THE OPERATION OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY IS SAFE FOR THE ENVIRONMENT AND THE POPULATION.

THE NUCLEAR WASTE MANAGEMENT METHODS OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY ARE ADEQUATE AND APPROPRIATE

The Applicant's nuclear facilities process high-level nuclear waste, spent nuclear fuel. Even though radiation protection is considered as well as possible, minor amounts of nuclear facility waste is generated at nuclear facilities due to direct radiation or contamination. Typically, nuclear facility waste comprises waste generated during operation, maintenance and plant modifications that has a level of radioactivity which prevents it from being decontaminated or cleared from regulatory control. Nuclear facility waste is divided into very low, low and intermediate-level waste, which are sorted, processed and packed appropriately. Dry nuclear facility waste is initially stored at the encapsulation plant, in the plant units' waste storage facilities, or they can be transferred according to their activity to either TVO's KAJ storage for intermediate-level waste or MAJ storage for low-level waste, after which it is placed in final disposal in the VLJ repository at Olkiluoto or in the disposal repository for low and intermediate level waste constructed later in connection with the disposal facility. Following interim storage, very low-level nuclear waste is placed in TVO's near-surface final disposal. The current operating licences for the Olkiluoto nuclear power plant allow for the processing and storage of nuclear facility waste.

The plan is to arrange the management of the nuclear facility waste and, at the end of the plant's service life, the decommissioning waste in a manner where radiation safety will not be jeopardised in the short or long term. An analysis of the planned actions for arranging nuclear waste management is presented in Appendix 4 to this application.

According to the articles of agreement for Posiva, the Applicant manages the processing and final disposal of spent nuclear fuel following the interim storage. Therefore, the Applicant has no need for the management of fresh nuclear fuel. The actions for which the Applicant is responsible and the rationale as regards spent nuclear fuel are presented in Appendix 4 to this application.

The low and intermediate-level nuclear facility waste generated in the Olkiluoto nuclear power plant area is placed in final disposal in the presently operating VLJ repository located at the plant site, for which TVO has been granted an operating licence on 9 April 1992. The operating licence is in force until the end of 2051, by which time a new operating licence will be applied for. The next periodic safety assessment of the VLJ repository will be performed by the end of 2021 and it will consider the nuclear facility waste generated by Posiva; the final disposal of Posiva's waste inside the VLJ repository will be made possible by amending the terms of the operating licence for the VLJ repository. The operating licence for the near-surface final disposal facility to be constructed at Olkiluoto will take into account the waste generated by Posiva.

Decommissioning waste from the encapsulation plant and disposal facility is largely similar to very low and low-level waste and, according to the current plans, it will be placed in final disposal in the VLJ repository or in the near-surface final disposal facility. Additionally, the Applicant has the option of constructing a separate disposal repository for this nuclear facility waste at a depth of approximately 180 metres along the driving tunnel of the disposal facility, in accordance with the construction licence. The decommissioning plan for Posiva's nuclear facilities contains plans for the dismantlement of the facilities and the storage and final disposal of the decommissioning waste.

More detailed descriptions of nuclear facility waste, the Applicant's plans and the available methods for arranging nuclear waste management, including the dismantlement of the nuclear facility and the final disposal of nuclear waste, as well as a description of the nuclear waste management schedule and its estimated costs are included in Appendix 4 to this application.

THE STORAGE AND FINAL DISPOSAL OF DIFFERENT TYPES OF NUCLEAR WASTE ARE MANAGED APPROPRIATELY.

THE APPLICANT HAS SUFFICIENT EXPERTISE AVAILABLE AND THE COMPETENCE OF THE OPERATING STAFF AND THE OPERATING ORGANISATION ARE APPROPRIATE

The Applicant has an operating organisation designed for operating the encapsulation plant and disposal facility, and it has access to sufficient, professional staff suited for their duties. The staff of the Applicant and the nuclear facility are trained, and additional training will be provided for their future duties. STUK approves the persons responsible for emergency preparedness arrangements, security arrangements and nuclear safeguards at the nuclear facilities and their deputies. During the design and construction of the Applicant's encapsulation plant and disposal facility, the Applicant has accrued substantial expertise in the construction of the nuclear facility and its planned operation. Furthermore, Olkiluoto is Finland's largest nuclear facility site where the diverse tasks have provided experience in working as a nuclear professional alongside TVO's personnel.

In recent years, Finland has been a leading country in the world as regards the final disposal of spent nuclear fuel. Via Posiva Solutions Oy, the Applicant's personnel have participated in domestic and international projects related to final disposal, which has further contributed to the competence of the Applicant's staff.

The operating staff of the encapsulation plant and disposal facility are being trained and qualified using procedures described in the YVL Guides. The rest of the operational support personnel are also trained and, if so required by the YVL Guides, qualified for their duties. The continuous training and qualification management of the operating organisation has been ensured by means of related training programmes. The Applicant's rules of procedure describe the most important operating tasks and responsibilities, and the rules of procedure must be approved by STUK before final disposal is started.

A more detailed description of the expertise available to the Applicant and the operating organisation is presented in Appendix 7 of this application.

THE APPLICANT HAS SUFFICIENT EXPERTISE AND THE OPERATING ORGANISATION IS APPROPRIATE.

POSIVA HAS THE FINANCIAL AND OTHER PREREQUISITES TO ENGAGE IN OPERATIONS SAFELY AND IN ACCORDANCE WITH FINLAND'S INTERNATIONAL CONTRACTUAL OBLIGATIONS

The Applicant's operations are funded by the Applicant's shareholders in accordance with the provisions of the articles of association and using commonly agreed cost division principles. In order to prepare for the eventuality that the operation of the Applicant's shareholders' nuclear power plants should suddenly cease, the parties under a nuclear waste management obligation have been, under the Nuclear Energy Act, obligated to collect a sum of money into the national nuclear waste management fund that can cover the management and final disposal activities of the existing nuclear waste. This amount of nuclear waste management liability is assessed annually in accordance with the provisions of the Nuclear Energy act.

The Applicant is not aware of any changes related to the operation of encapsulation plant and disposal facility at Olkiluoto resulting from legislation or international agreements that would substantially affect the Applicant's prerequisites for operating the encapsulation plant and disposal facility safely and in line with Finland's obligations under international agreements.

The Applicant's financial prerequisites to engage in operations are presented in Appendices 8 and 9. The other necessary prerequisites to engage in operations safely and in accordance with Finland's international contractual obligations are presented in Appendix 5.

The Applicant has in place sufficient security arrangements, emergency preparedness arrangements and other arrangements for limiting nuclear damage and protecting the use of nuclear energy from activities that endanger nuclear or radiation safety. A more detailed description of the Applicant's security and emergency preparedness arrangements is presented in Appendix 5.

The Applicant has taken out liability insurance concerning the encapsulation plant and disposal facility, as required by the Nuclear Liability Act (484/1972), which enters into force when the prerequisites in the Act are met.

ON THE BASIS OF WHAT HAS BEEN PRESENTED HEREINABOVE AND IN THE MORE DETAILED REPORTS ENCLOSED WITH THIS APPLICATION, THE APPLICANT CONSIDERS THAT THE PREREQUISITES FOR GRANTING A LICENCE REFERRED TO IN SECTION 20 OF THE NUCLEAR ENERGY ACT AND THE REQUIREMENTS IN SECTIONS 5 TO 7 OF THE NUCLEAR ENERGY ACT CONCERNING THE OVERALL GOOD OF SOCIETY AND THE SAFETY OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY ARE MET AND THAT THE OPERATING LICENCE APPLIED FOR BY THE APPLICANT MAY BE GRANTED.

REPORTS REQUIRED BY SECTION 34 OF THE NUCLEAR ENERGY DECREE

Appendix 1.	Extract from Trade Register (separate appendix, not included in this hard copy version)
Appendix 2.	Duplicate of articles of association and shareholder registry (separate appendix, not included in this hard copy version)
Appendix 3.	Description of settlement and other activities on the nuclear facility site and in its vicinity, including land use planning arrangements
Appendix 4.	Description of nuclear waste management
Appendix 5.	A general description of the technical operating principles and solutions and other arrangements implemented to ensure safety as well as a description of the applied safety principles and an assessment of their implementation
Appendix 6.	Description of the actions taken in order to limit the environmental load caused by the nuclear facility
Appendix 7.	Description of the expertise available to the applicant and the nuclear facility's operating organisation
Appendix 8.	Description of the applicant's financial standing, the management plan for the financing and the production plan
Appendix 9.	The applicant's financial statements from 1999–2015 (separate appendix, not included in this hard copy version)
Appendix 10.	Updated report on the environmental impacts of the plant complex
Appendix 11.	Updated analysis of the retrievability of the spent nuclear fuel
Appendix 12.	Updated analysis of the risks related to the transport of spent nuclear fuel
Appendix 13.	Changes made to the project following the granting of the construction licence
Appendix 14.	Report on how the applicant has adhered to the conditions of the construction licence

01

EXTRACT FROM TRADE REGISTER

(SEPARATE APPENDIX, NOT INCLUDED
IN THIS HARD COPY VERSION)

02

DUPLICATE OF ARTICLES OF ASSOCIATION
AND SHAREHOLDER REGISTRY

(SEPARATE APPENDIX, NOT INCLUDED IN
THIS HARD COPY VERSION)

03

DESCRIPTION OF SETTLEMENT AND OTHER ACTIVITIES ON THE NUCLEAR FACILITY SITE AND IN ITS VICINITY, INCLUDING LAND USE PLANNING ARRANGEMENTS

PHOTO: Posiva Oy

TABLE OF CONTENTS

1. GENERAL

Posiva's nuclear waste encapsulation plant and disposal facility will be built on the island of Olkiluoto in southwestern Finland. The island of Olkiluoto is located in the municipality of Eurajoki, approximately 13 kilometres north of Rauma and approximately 34 kilometres southwest of Pori. Olkiluoto is a large island (approximately 12 km^2), separated from the mainland by a small strait. The encapsulation plant will be located in the central part of the island in the Posiva nuclear facility area (Figure 2). The spent fuel disposal facility will be located at a depth of approximately 430 m in the central parts of the island. According to a decision-in-principle made by the Finnish Government in 2000, the location of the spent nuclear fuel encapsulation plant and disposal facility is Olkiluoto Island in Eurajoki; Figure 1 shows the location of Eurajoki in Finland.

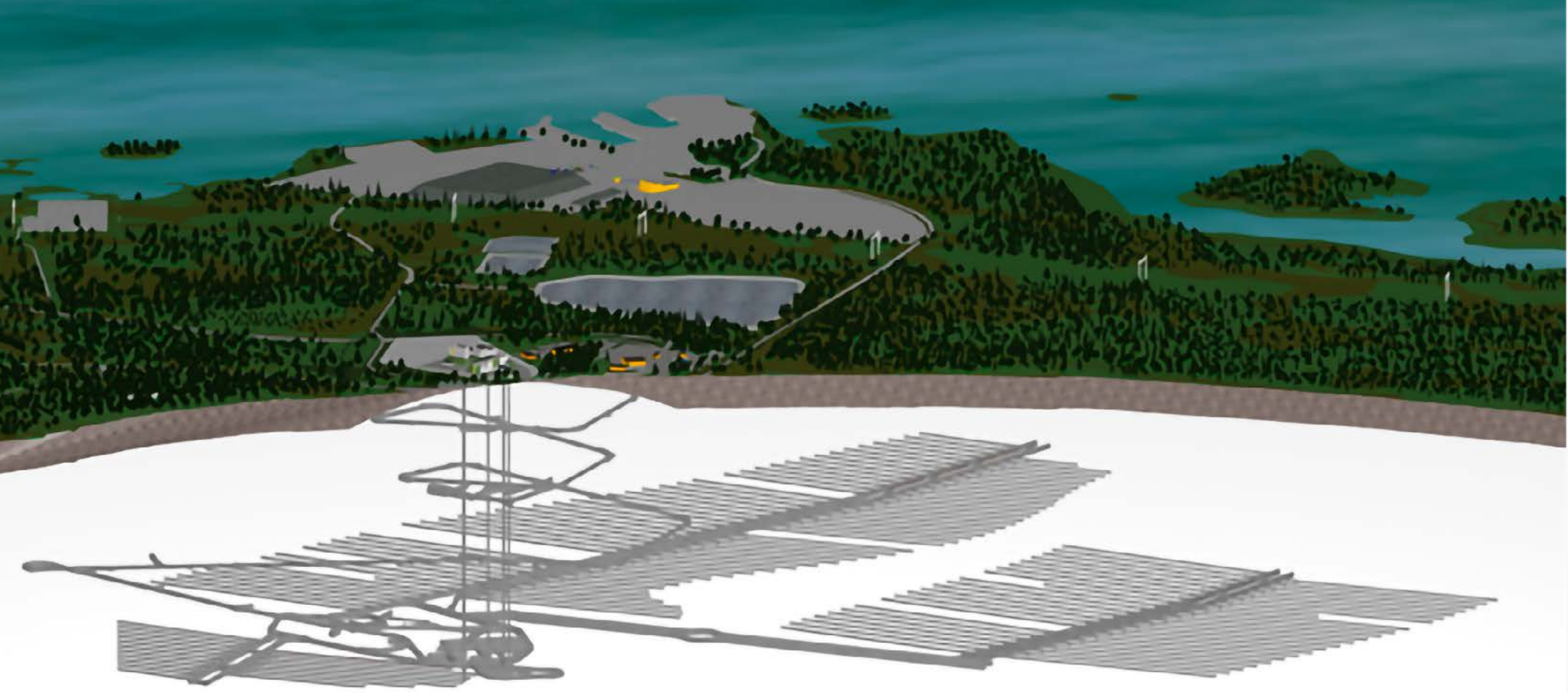
Figure 1. Location of Eurajoki.

The location of the encapsulation plant and disposal facility of Posiva Oy (Posiva) meets the requirements for land use set out in legislation and in the guidelines for nuclear power plants (YVL Guides) issued by the Radiation and Nuclear Safety Authority. Land use in the Olkiluoto power plant area is presently controlled by the provincial plan, the partial master plan for Olkiluoto and local detailed plans that have been validated in 2014. In the Olkiluoto area, an amendment to the local detailed plan is underway in 2021, which will enable, among other things, the near-surface final disposal of very low-level nuclear waste. The amendment affects an area approximately one kilometre north of the nuclear power plant units, so the local detailed plan amendment project does not apply to the Posiva area. The settlement in the Olkiluoto area is mainly holiday homes. The larger population centres with permanent settlement, the centres of Eurajoki and Rauma, are located at a distance of approximately 15–20 kilometres from Olkiluoto. Auxiliary and support activities related to electricity generation and nuclear waste management will be built on Olkiluoto Island, and thus the infrastructure will be renewed and supplemented to meet the needs of safe and efficient energy supply.

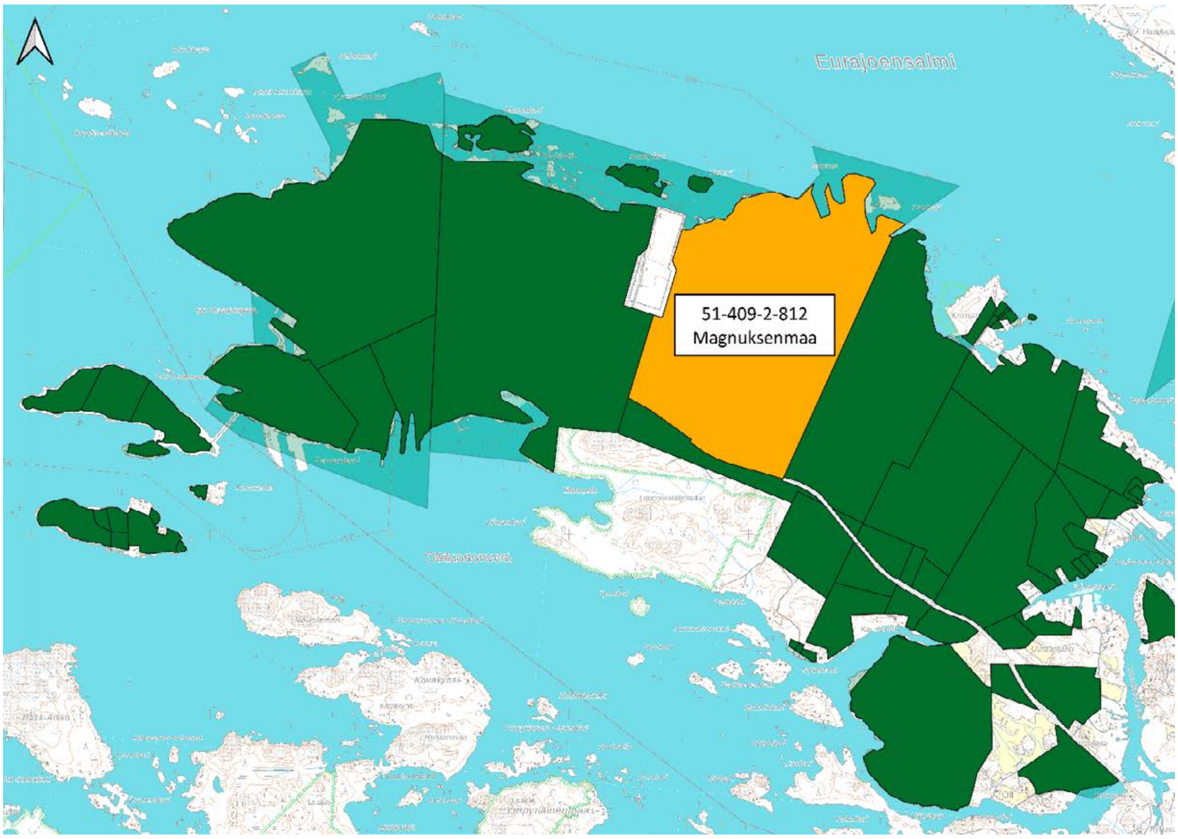
In the Olkiluoto partial master plan, the area of the underground disposal repository is limited to the whole of Olkiluoto Island and parts of its adjacent water areas, except for the holiday settlement area in the east. The final disposal area defined in the partial master plan is defined in more detail in the local detailed plan for the area. The construction of the underground disposal facility in the local detailed plan area will initially focus on the vicinity of the ONKALO® underground research facility already built, and will expand in later phases according to bedrock conditions (Figures 3 and 4). In addition to bedrock conditions, the final location of the underground facilities is affected by the design principle agreed between Teollisuuden Voima Oyj (TVO) and Posiva, where Posiva refrains from designing underground disposal repositories in the bedrock of the area reserved for the construction of nuclear power plant units.

Figure 2. Wintertime aerial view of the Posiva plant site. At the rear in the figure is a ventilation building and the encapsulation plant under construction. The disposal facility is located approximately 430 metres below the encapsulation plant. In the foreground are Onkalo's driving ramp, Posiva's project office building and other support buildings for Posiva's operations. The Olkiluoto nuclear power plant units are located approximately two kilometres west of the Posiva area. The Korvensuo raw water area in the foreground serves the water needs of the Olkiluoto area.

Figure 3. The disposal repository intended for 6,500 tU of spent fuel positioned in the local detailed plan area with the border of the local detailed plan area in red.



■ **Figure 4.** The location of ONKALO and the disposal facility in the bedrock of Olkiluoto. An over/underground visualisation of the Posiva plant area. The figure shows the planned disposal repository for 6,500 tU of spent nuclear fuel.



■ **Figure 5.** The land owned by TVO at Olkiluoto is marked on the map in dark green and orange. The area leased by Posiva from TVO is located in the part marked in orange, in Magnuksenmaa. Posiva Oy; source: National Land Survey of Finland, land register map 2020.

TVO owns the areas related to the applicant's above-ground and underground activities (Figure 5). Posiva has entered into a long-term lease agreement with TVO, under which the areas owned by TVO at Olkiluoto in Eurajoki will be available for the construction of the encapsulation plant and disposal facility. The Liiklankari conservation area in the southern part of Olkiluoto Island is owned and managed by Metsähallitus. The area is bordered on its northern part by the local detailed plan area.

2. SETTLEMENT AND OTHER ACTIVITIES

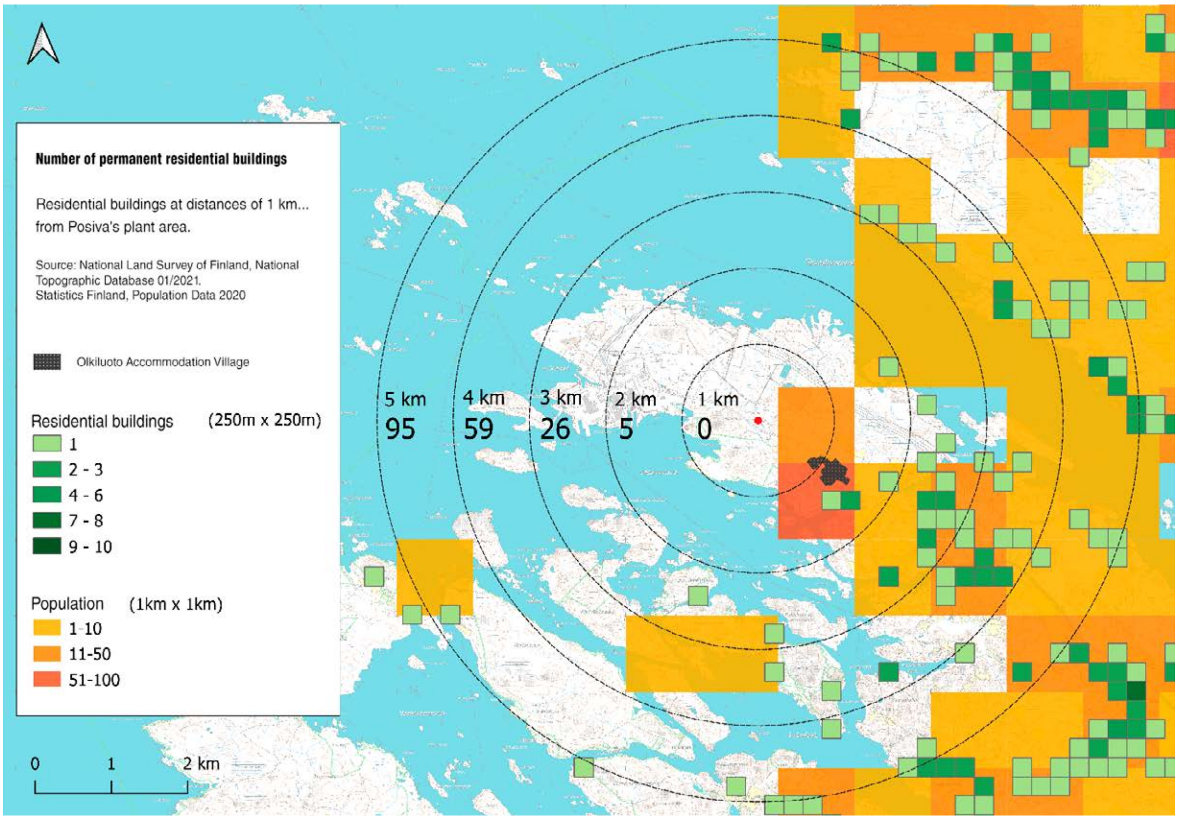
2.1 ACTIVITIES IN THE OLKILUOTO AREA

Posiva has built a spent nuclear fuel encapsulation plant and disposal facility in an area owned by TVO and managed by Posiva in the central part of Olkiluoto Island in the municipality of Eurajoki. Construction of the research facility (ONKALO®) related to the encapsulation plant and disposal facility began in 2004; ONKALO will be integrated into the disposal facility.

The project office, research hall and maintenance and storage hall for Posiva's equipment, which were built during the construction phase of the ONKALO research facility, are located in the final disposal area. The ventilation and lifting equipment buildings related to the operations of the disposal facility are also located in the area. An encapsulation plant is under construction in the area, where spent nuclear fuel will be enclosed inside canisters before the final disposal at a depth of approximately 430 metres. In the area, there is also a fire water pumping station and contractors' areas, as well as the Korvensuo raw water basin.

The activities closest to Posiva's area are the Olkiluoto 1 and Olkiluoto 2 nuclear power plant units at the western end of the Olkiluoto power plant area, which have been generating electricity for approximately 40 years. The nominal net power output of these plant units is 890 MWe. The Olkiluoto 3 plant unit, which has a nominal net power output of 1,600 MWe, is also located in the power plant area.

The plant area also contains administrative buildings, a training and visitor centre, storage facilities, workshops, and auxiliary heating plant, a raw water purification plant, a water



■ **Figure 6.** Number of permanent residential buildings (cumulatively) less than 5 km from the Posiva plant site. (Image: Posiva Oy; source: Terrain database of the National Land Survey of Finland, 01/2021 (building class classification, 9 December 2019)).

demineralisation plant, a sanitary water purification plant, an accommodation village, a landfill and a spent fuel interim storage (KPA storage), interim storages for low and intermediate-level power plant waste (MAJ and KAJ storages), an operating waste repository (VLJ cave) and a disposal repository for very low-level nuclear facility waste (near-surface final disposal).

The northern shore of the island of Olkiluoto has a dock and port which are located on land that is owned by the applicant. The Posiva area is located south of the port. The port is open to public use, and it has a six-metre deep shipping channel leading to it that is maintained by the Finnish Transport Agency. Between 5 and 10 people are employed by the port's different functions.

2.2 SETTLEMENTS IN THE VICINITY OF OLKILUOTO

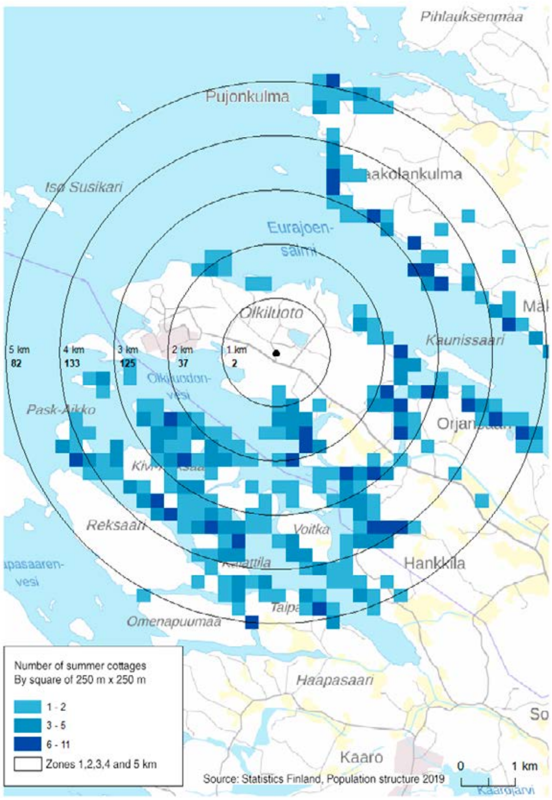


Figure 7. Number of holiday homes less than 5 km from the Posiva plant site, 2019, shown as number of homes in zones 0–1 km, 1–2 km, 2–3 km, 3–4 km and 4–5 km. Source: Statistics Finland.

Within five kilometres of the Posiva plant area, there are 95 permanent residential buildings (Figure 7) and 379 holiday homes (Figure 8), as well as the Olkiluoto accommodation village. The nearest permanent residential buildings are on the island of Olkiluoto, and mainly in the village of Ilavainen on the east side of the island of Olkiluoto. There are less than ten buildings suitable for permanent residence on the island of Olkiluoto. There are also approximately 30 holiday homes in the eastern part of the island. On 31 December 2019, a total of approximately 80 inhabitants, including the residents of the Olkiluoto accommodation village, lived permanently less than five kilometres from the Posiva plant area.

In the accommodation village of Olkiluoto, it is currently possible to arrange temporary accommodation for the needs of TVO and Posiva for 553 persons. In addition, there are 24 places for motor homes in the area. Near the accommodation village in the eastern part of the island of Olkiluoto is the Raunela estate, whose buildings and surroundings TVO has restored to correspond to the situation at Olkiluoto before the arrival of the nuclear power plant.

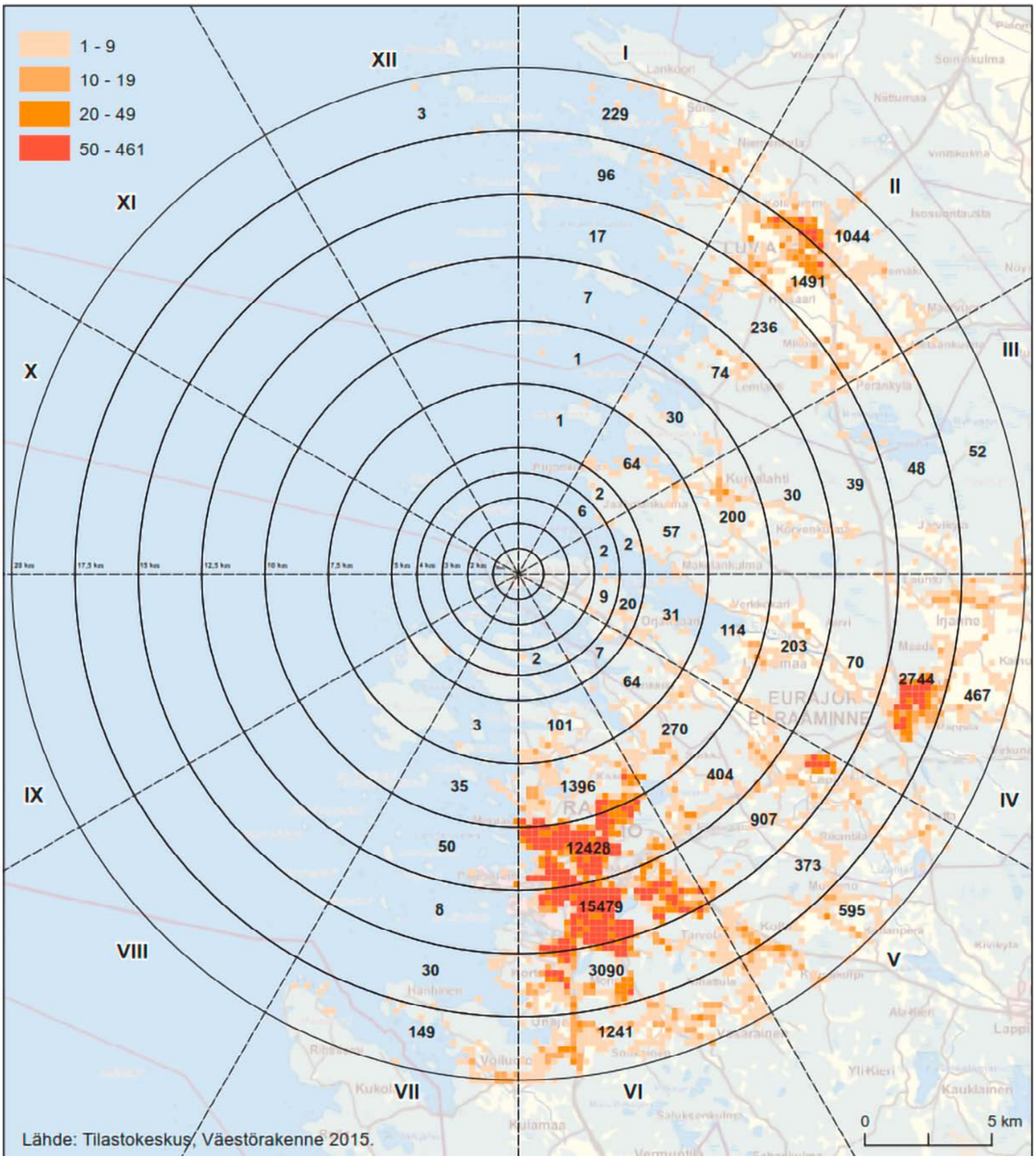
Agglomerations

Eurajoki is a coastal municipality located on the shore of the Gulf of Bothnia, and it is part of the economic zone of Rauma. The municipality of Eurajoki has approximately 9,400 inhabitants. The municipal centre is located along national road 8, approximately 15 kilometres north of the centre of Rauma and approximately 35 kilometres south of Pori. Figure 8 presents the location of Olkiluoto within Eurajoki and in relation to Rauma.

On 31 December 2020, the neighbouring municipalities of Eurajoki are as follows (Association of Finnish Municipalities, https://www.kuntaliitto.fi/talous/kuntatalouden-tilastot/kuntien-vaestotiedot):

- Rauma (approx. 39,000 inhabitants)
- Eura (approx. 11,500 inhabitants)
- Nakkila (approx. 5,300 inhabitants)
- Pori (approx. 83,700 inhabitants)

■ **Figure 8.** Olkiluoto is located approximately 20 km away from the significant population centres, Rauma and Eurajoki.



■ **Figure 9**. Population (31 December 2014) by sector and squares of 250 x 250 m in the surrounding areas of Olkiluoto, distances between 0 and 20 km.

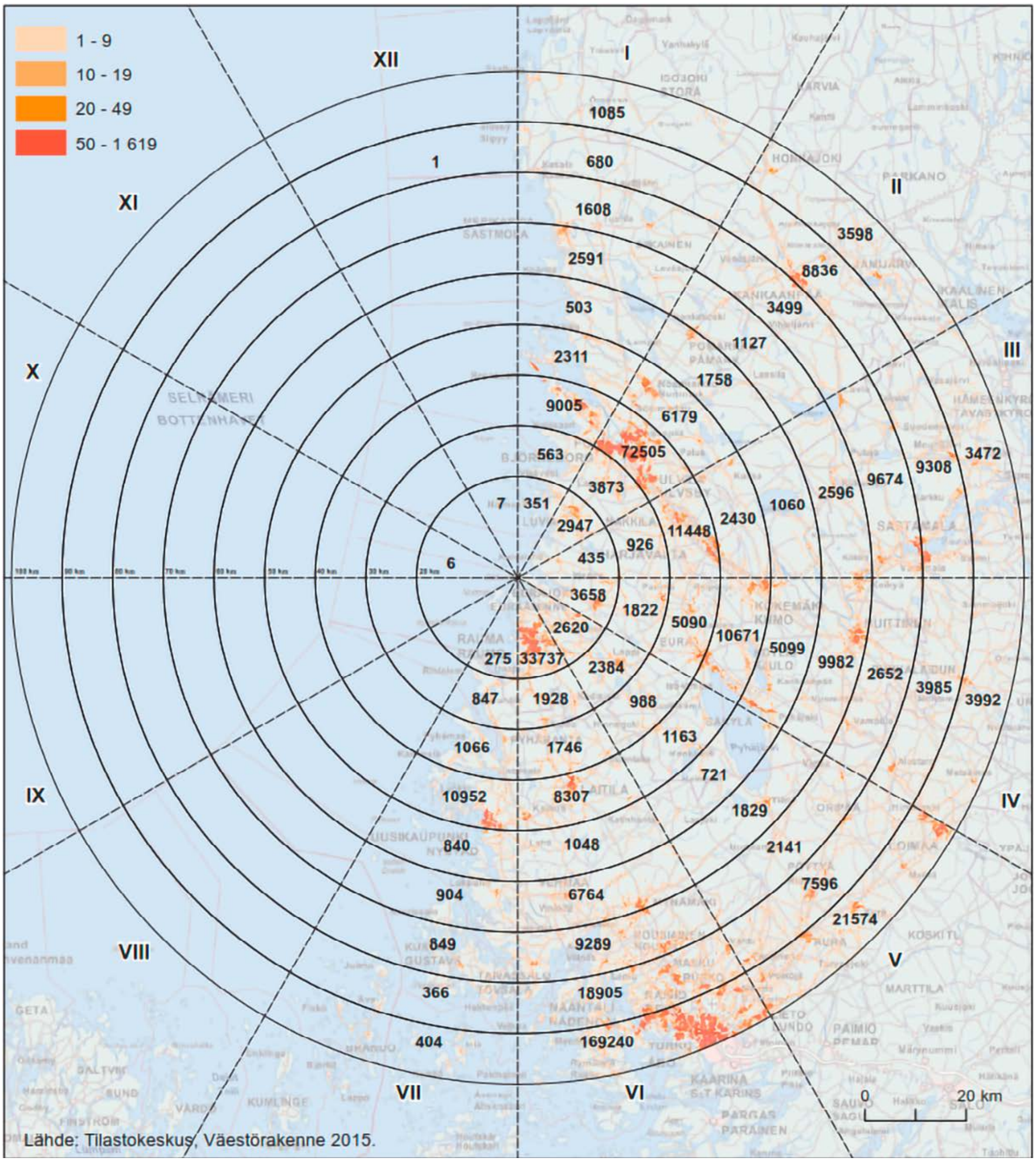


Figure 10. Population (31 December 2014) by sector and squares of 250 x 250 m in the surrounding areas of Olkiluoto, distances between 0 and 100 km.

The Rauma region, which consists of Eura, Eurajoki, Säkylä and Rauma, has approximately 69,000 inhabitants. The Pori region (Harjavalta, Huittinen, Kokemäki, Merikarvia, Nakkila, Pomarkku, Pori and Ulvila), located northeast and east of Olkiluoto, has approximately 130,000 inhabitants.

Figures 9 and 10 present the distribution of settlements around the nuclear power plant (at distances between 0–20 km and 0–100 km). The figures are based on data from Statistics Finland, and they describe the situation as of 31 December 2014.

2.3 OTHER ACTIVITIES IN THE SURROUNDING AREAS OF OLKILUOTO

Only a small amount of agricultural activities takes place near the power plant area at Olkiluoto. There are small cultivated plots in the eastern part of the island. The nearby waters are used for recreational fishing.

The villages of Ilavainen and Orjasaari, which are located to the east of the island of Olkiluoto (5-km radius), have very few activities and the power plant area does not significantly affect them. Traffic through the villages to Olkiluoto was heavier previously, during the construction and commissioning of the Olkiluoto 3 plant unit and during the construction of Posiva's nuclear waste facilities, but traffic volumes have since decreased.

Services, refining, agriculture and forestry are important areas in the economic structure of the municipality of Eurajoki. TVO is the largest employer in the municipality. The applicant employs approximately 90 persons, in addition to which approximately 100 persons work on Posiva's projects. Among others, these include personnel from TVO and various design offices.

In 2018, the fields of business employing the inhabitants of Eurajoki were divided as follows:

- primary production 4.6%
- refining 47.8%
- services 46.8%.

Half of the inhabitants of Eurajoki work outside of the municipality, such as in Rauma or Pori. People coming to work at Eurajoki arrive from a wide area, but the majority live in Rauma.

The Olkiluoto power plant area has a significant direct and indirect effect in the province of Satakunta and in the Rauma region in particular. In 2020, 49% of those employed by TVO at Olkiluoto lived in Rauma, 18% lived in Eurajoki, 20% lived in Pori and 5% lived in other municipalities.

The most important farm lands in the nearby areas of Olkiluoto are located 20–40 km to the east of the power plant and 25–35 km to the northeast. There are a few commercial gardens located approximately 10 kilometres from the power plant that produce vegetables mainly for the Rauma region. The nearest dairy is located in Ulvila at a distance of approximately 35 kilometres. There are three milk-producing farms within a 10-kilometre radius of the nuclear power plant. There are several dozen milk farms within a 40-kilometre radius from the power plant.

There is food industry in the vicinity of Olkiluoto (less than 20 km). Along Highway 8 in Rauma there is a HKScan unit where poultry is slaughtered and meat is cut and packaged. The other closest industrial plants related to food production are in Eura and Säkylä. In addition, 21 km away, at Lappi in Rauma, is Kivikylän Kotipalvaamo, where processed meat is produced.

The most regionally important groundwater areas are located in Eurajoki outside the protection zone of the plant area. The groundwater areas of Kuivalahti, Metsäkulma, Korvenkulma, Irjante, Mullila, Kotkajärvi, Juvamäki and Hanninmäki are located less than 20 km from the plant area. The Nihtiö and Pässi groundwater areas are located 25 km from the plant area in Pyhäranta and Nakkila. Water for domestic and industrial use in the Rauma area is taken from both the Eura and Lapinjoki rivers. Industrial wastewater is discharged into Eurajoki. The own domestic water of the Olkiluoto nuclear power plant area is produced in Olkiluoto from the Korvensuo basin, to which water is pumped from Eurajoki.

Four schools are located within a radius of approximately 10 kilometres from the nuclear power plant. These are primary schools whose pupils are between 6 and 13 years old.

3. LAND USE PLANNING ARRANGEMENTS AND OTHER ARRANGEMENTS

3.1 GENERAL

Olkiluoto has a valid provincial plan, master plan for shore areas, master plan and local detailed plans that indicate areas for the construction of nuclear facilities. These plans have been updated to correspond with the content requirements of the new Land Use and Building Act and to take into account the requirements for the spent nuclear fuel disposal facility.

The land owned by TVO in Olkiluoto is zoned for energy production, and there are restrictions on disposal and land use in the vicinity. There is a protection zone of approximately 5 km around the nuclear power plant, where all non-nuclear activities are restricted. It is in this area that the encapsulation plants and disposal facilities will operate.

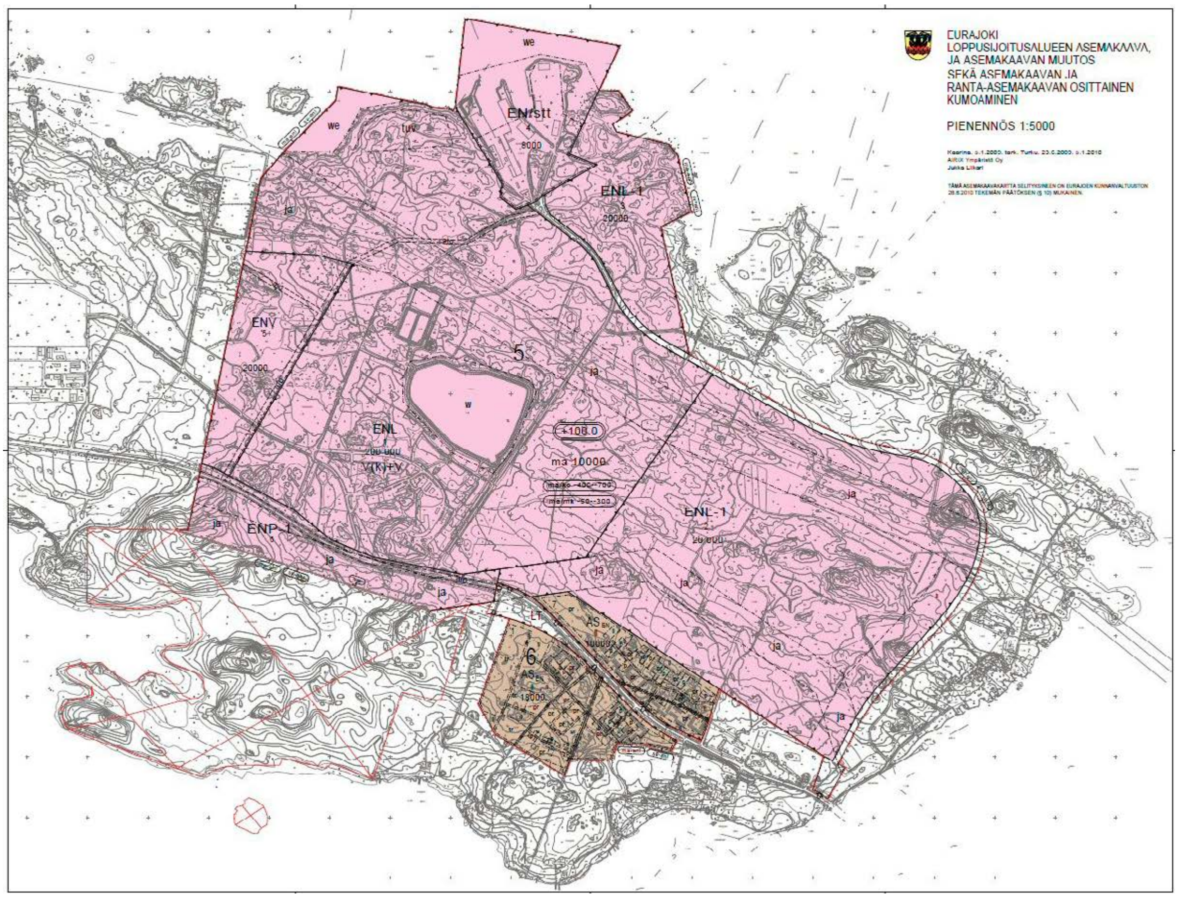
3.2 LOCAL DETAILED PLAN

Local detailed plan for the final disposal area

The municipality of Eurajoki approved the local detailed plan and local detailed plan amendment for the final disposal area via its decision on 28 June 2010. The decision also included the partial overturning of the local detailed plan and local detailed plan for shore areas. The plan indicates the areas and permitted building volumes for the buildings and structures of the disposal facility and the supporting functions for the facility.

Local detailed plans for Olkiluoto

The valid local detailed plans for Olkiluoto have a permitted building volume of 6.55 million cubic metres in the area designated for use as a nuclear



■ **Figure 11.** Local detailed plan for the final disposal area.

power plant area; nearly 4 million cubic metres are available for future construction. The power plant area is located in the western end of the island of Olkiluoto.

The local detailed plan (5 March 2011) also defines the area of the disposal facility. Construction work can be carried out in the bedrock of the area in accordance with the construction licence issued under the Nuclear Energy Act for the high-level waste disposal facility. The extent of the area is determined by the occurrence of the bedrock most favourable for final disposal at the final disposal depth.

The local detailed plan that is valid in the area of the current nuclear power plant units and Olkiluoto 3 has been confirmed in 1997 and determined as up-to-date in 2014. The power plant area is marked as block area for industrial buildings and storage buildings *into which the construction of nuclear power plants and other facilities and equipment intended for the generation, distribution and transfer of energy and their related buildings, structures and equipment may be constructed unless this has otherwise been limited.*

The majority of the water areas referred to in the local detailed plan have been confirmed as water areas *that may be used for the purposes of power plants and on which quays and other structures and equipment required by power plants may be built near the industrial and storage areas.* The plan also indicates the water areas where filling and embankment works are permitted.

Furthermore, the Olkiluoto area has block area plans confirmed in 2005 for the accommodation buildings serving energy generation, and earlier local detailed plans for shore areas concerning the eastern part Olkiluoto Island.

An amendment to the local detailed plan for the old accommodation village in the Olkiluoto area is pending. The accommodation village was moved to a new location at the turn of the millennium, and it is now desired to use the old area for other activities.

3.3 MASTER PLANS

The modification of the partial master plan at Olkiluoto started in 2006, and the plan came into force in 2010. The plan covers Olkiluoto in Eurajoki, the small islands (Kornamaa, Mäntykari, Munakari and approximately 20 smaller islands) to the north and northwest of Olkiluoto and the surrounding waters.

The most important goal of the partial master plan has been to maintain the land use prerequisites in the largest energy generation area in Finland, and to reserve areas for implementing the final disposal of spent nuclear fuel in accordance with the Finnish legislation and the requirements set for the safety of operations.

In the waterfront areas of Rauma, the partial master plan for the northern shores of Rauma, approved in 1999, and its amendment are in force. The town council of Rauma approved the amendment of the partial master plan for Rauma's northern shore areas on 29 September 2008. The plan is legally valid. The plan covers Kuusisenmaa, Leppäkarta, Lippo and Vähä-Kaalonperä and the waters surrounding these islands.

In December 2005, the municipal council of Eurajoki approved an amendment of the master plan for shore areas that reserved areas for an accommodation village and other functions serving energy generation in the southeast part of the island of Olkiluoto.

Master plan for shore areas in Eurajoki and its amendment

The purpose of the plan amendment started in 2010 is to verify the master plan for shore areas in Eurajoki to correspond to the current legislation and the present needs.

The plant area at Olkiluoto (energy management area) and the Natura area are not included in the amendment of the master plan for shore areas, since a partial master plan was approved for these areas in May 2008. The holiday home areas on the eastern shores of Olkiluoto, the areas reserved for year-round habitation and their hinterlands are included in the plan amendment, since the goals of the plan amendment involve the building sites.

3.4 PROVINCIAL PLAN

The Satakunta provincial plan (legally valid 2013), Satakunta phased provincial plan 1

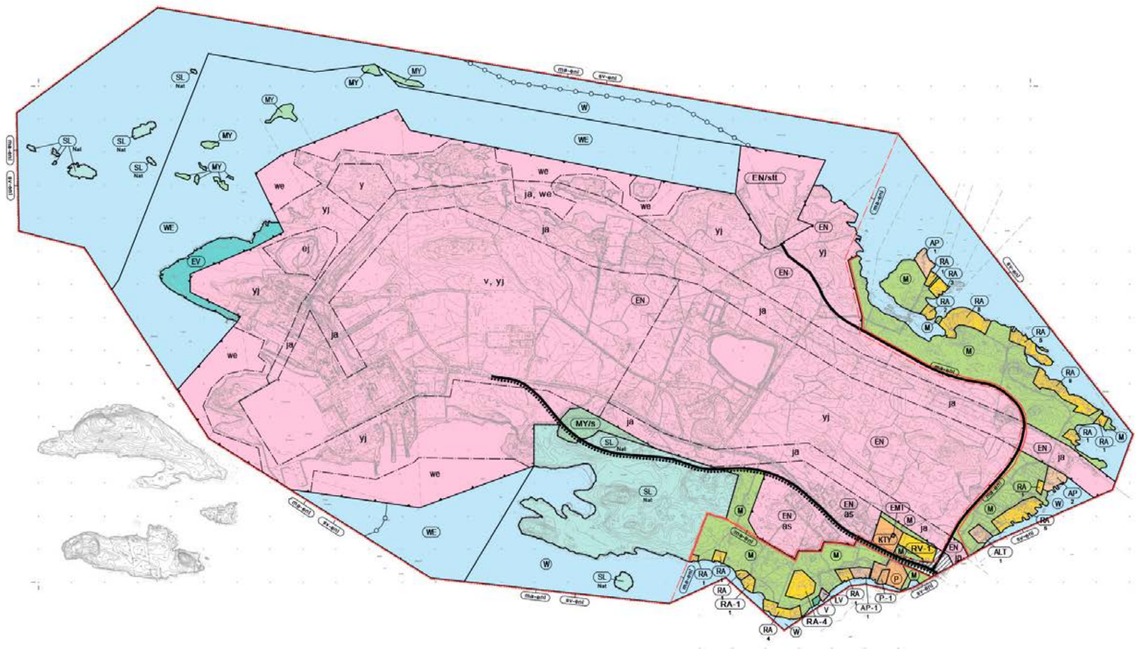


Figure 12. Olkiluoto partial master plan.

(legally valid 2016) and Satakunta phased provincial plan 2 (legally valid 2019) are in force in the area. With the entry into force of the Satakunta phased provincial plan 2, the corresponding entries and regulations in the Satakunta provincial plan were repealed. The provincial plan supports power plant construction at Olkiluoto.

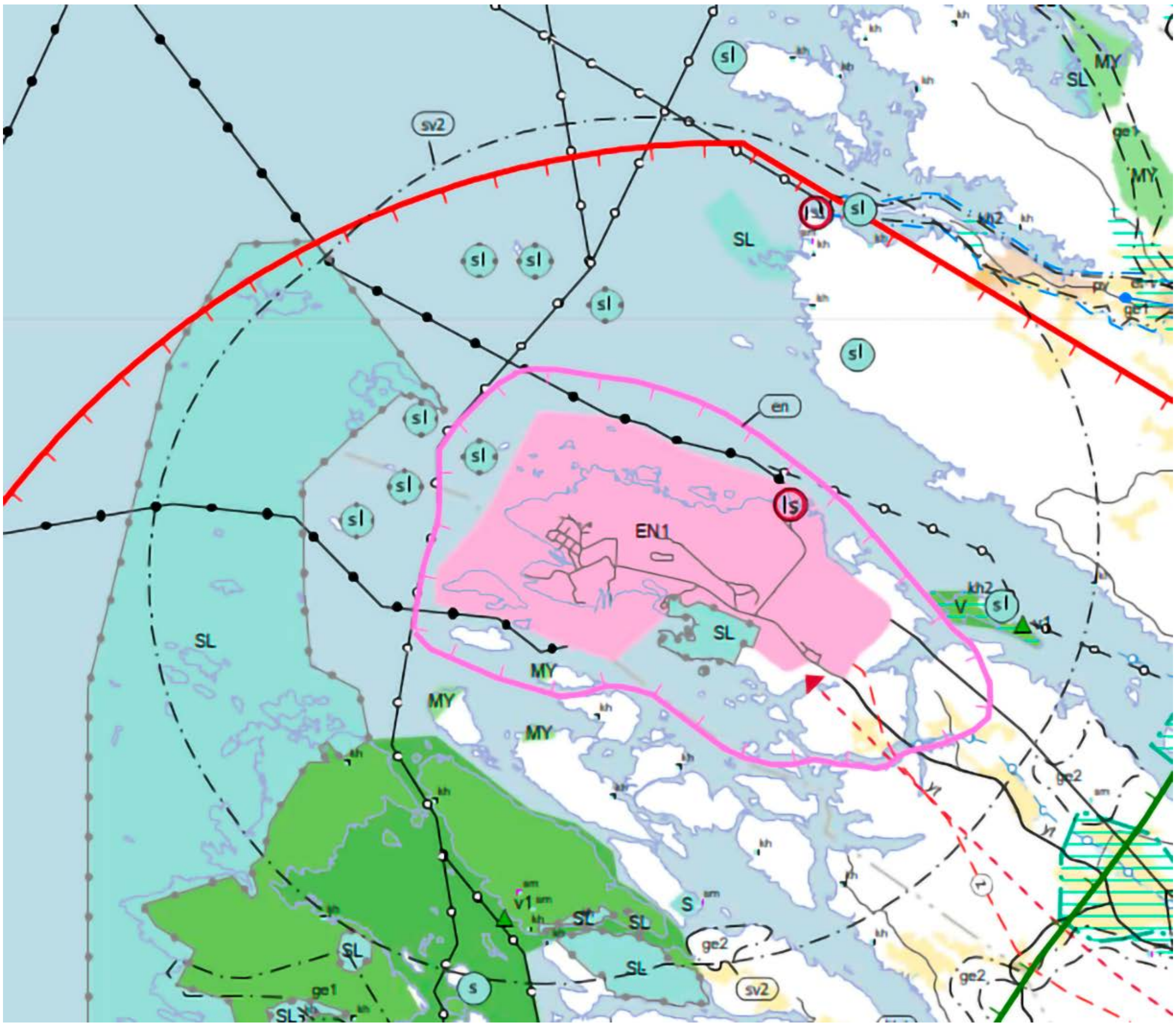
The provincial plan takes into account the goals set for Olkiluoto's land use planning by the Finnish Government and the requirements of nuclear waste management. In the provincial plan, the power plant area at Olkiluoto is marked as an area of community management (ET). In addition, the plan indicates a zone of energy management (EN1) for the Olkiluoto area; this is used to establish a nuclear power plant site area for facilities, buildings and structures serving energy generation and facilities and buildings implementing the final disposal of spent nuclear fuel. An area for the development of energy management (en) is located around the plant area; development needs related to land use are focused in this area due to the energy management functions. The outermost area is a precautionary action zone (sv2) for the nuclear power plants. The provincial plan also indicates the power line routes leaving the area, the regional road, shipping and sailing routes and the conservation areas in the area. A construction restriction is in force in the area in accordance with Section 33 of the Land Use and Building Act (132/1999).

The provincial plan sets forth that special attention should be paid to matters of environmental protection, and that the processing and storage of radioactive waste should be arranged with absolute safety. The provincial plan also allows for constructing other energy generation capacity and other industry based on the energy generation in the region. The Liiklankari area is a nature reserve in the provincial plan.

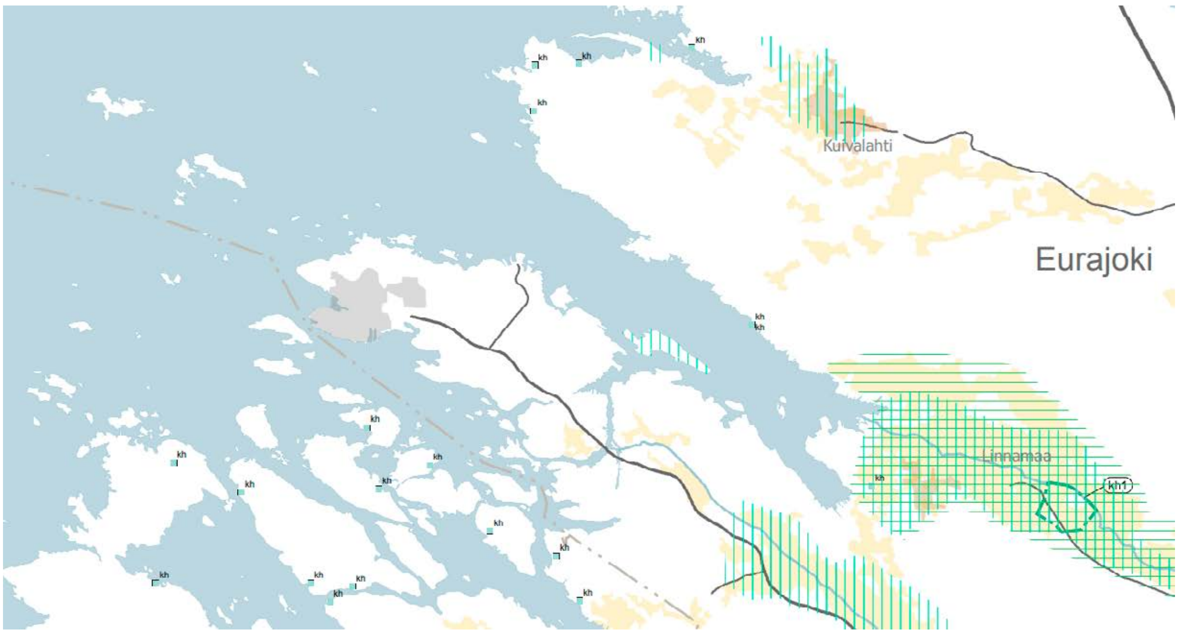
In the Satakunta phased provincial plan 1, no designations have been assigned to the project area or its immediate vicinity. In the phased provincial plan 2, the Olkiluoto area has been designated as an industrial and service area. In addition, the nearest provincially significant cultural sites (less than 10 ha) are approximately 1.6 km to the south and approximately 2.5 km to the northeast.

3.5 PRECAUTIONARY ACTION ZONES

The YVL Guides of the Radiation and Nuclear Safety Authority define the protective areas surrounding the plant area of a nuclear power plant. The Posiva plant area is located in the



■ **Figure 13.** Excerpt from the Satakunta provincial plan. Source: Satakuntaliitto 2020.



■ **Figure 14.** Excerpt from the Satakunta phased provincial plan 2. Source: Satakuntaliitto 2020.

Olkiluoto nuclear power plant area. Posiva's plant area is relatively small in size, and there are two partially nested areas demarcated by the plant fence.

The precautionary action zone of the Olkiluoto nuclear power plant, inside which the areas leased by Posiva from TVO are located, extends to approximately five kilometres' distance from the facility. There are land use restrictions in force in the precautionary action zone. The precautionary action zone does not contain facilities inhabited or visited by a considerable number of people, such as schools, hospitals, care facilities, shops, or significant places of employment and accommodation that are not related to the nuclear power plant. The precautionary action zone does not contain socially significant functions that could be affected by an accident at the nuclear power plant. The precautionary action zone of the disposal facility has been defined in the partial master plan. When excavating and drilling the bedrock in the area, it must be taken into account that the area is in the precautionary action zone of the disposal facility. Before excavation and drilling of the bedrock, the party carrying out the final disposal activity must be consulted.

The number of permanent inhabitants, recreational housing, and recreational activities shall be limited inside the precautionary action zone of a nuclear power plant, so that a rescue plan that allows for effective evacuation of the population may be drawn up and implemented for the area. Special attention shall be paid to the characteristics of the site's immediate surroundings, such as archipelagos that are difficult to travel and recreational settlements, for example, as well as other rescue activities that may be required under exceptional conditions.

Primarily, land use and construction decisions shall aim at maintaining the number of permanent and leisure-time inhabitants inside the precautionary action zone at a level where it will not substantially increase during the construction and operation of a nuclear power plant from the time when the decision-in-principle was made under the Nuclear Energy Act.

An emergency planning zone extending to about 20 kilometres from the facility has been defined; the zone shall be covered by a detailed external rescue plan for the protection of the public drawn up by authorities. The precautionary action zone is part of the emergency planning zone.

The conditions set for precautionary action zones are met at Olkiluoto. The number of permanent inhabitants inside the precautionary action zone does not prevent effective rescue operations. Any activities that may jeopardise the safety of the plant unit have been moved sufficiently far. Limitations apply to land use in the nearby areas. Preparations have been made for the supervision of movement and transport within an area of limited movement and sojourn in accordance with the Ministry of the Interior's Decree (709/2003) and the site area itself.

Pursuant to Section 63(1)(6) of the Nuclear Energy Act, in the 2120s or when the property has a permanently closed spent nuclear fuel disposal repository, the Radiation and Nuclear Safety Authority is authorised to issue prohibitions on measures regarding the property in order to ensure safety. Pursuant to Section 85 of the Nuclear Energy Decree, STUK must notify the location of the final disposal of nuclear waste as well as the prohibition referred to above for entry in the cadastre or land register.

3.6 CONSERVATION AREAS, NATURA AREAS

Natura areas, nature reserves, nature conservation programme sites and other nationally valuable nature sites (SYKE 2021) located within a radius of around five kilometres are shown in Figure 15 and Table 1 below. The operation of the Olkiluoto nuclear facilities has not caused significant harm to the habitat types protected by the Natura areas, which means that it has been possible to undertake the construction of the infrastructure needed by the nuclear facilities in harmony with the state of the environment and without unnecessarily jeopardising the natural and environmental values. Posiva has implemented EIA procedures for the final disposal of spent nuclear fuel, which in the statement of the Ministry of Trade and Industry were considered to be in accordance with the Act on Environmental Impact Assessment.

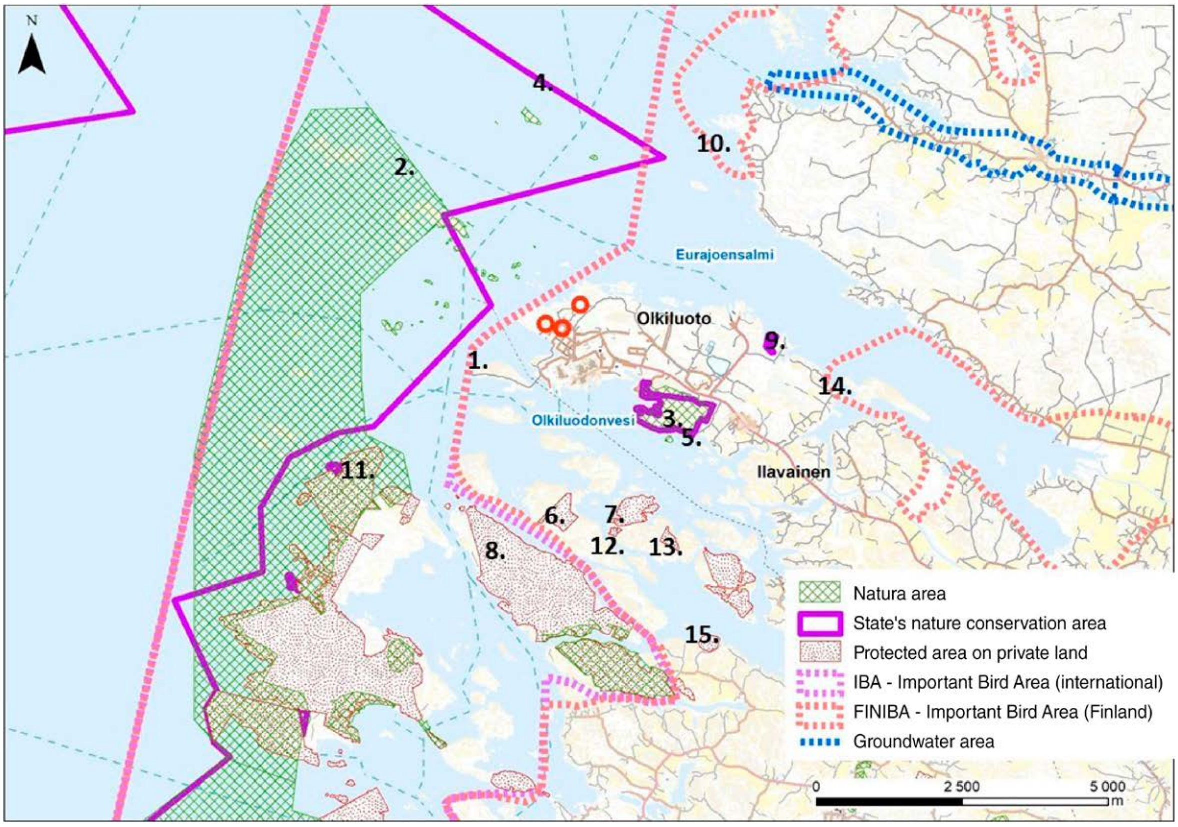


Figure 15. Natura 2000 sites, nature reserves and nationally valuable nature sites located in Eurajoki. The numbering extends 5 km from the Olkiluoto power plant area.

1. Rauma-Luvia archipelago IBA area (27,360 ha) and Rauma–Luvia–Pori archipelago FINIBA area (27,371 ha). The Rauma-Luvia archipelago, one of Finland's internationally important IBA bird areas, is a large, unified archipelago and an important seabird nesting area. The area is part of the Rauma–Luvia–Pori archipelago, one of Finland's important FINIBA bird areas (Leivo et al. 2002).
2. Rauma archipelago Natura area (FI0200073, SAC, 5,350 ha). The Natura area includes the outer archipelago of the Bothnian Sea and the archipelago of the sea zone, which are important for seabirds. It also includes parts of the inner archipelago, which contain, among other things, groves that are valuable in terms of their vegetation (Southwest Finland ELY Centre 2013a). The nearest small islands in front of Olkiluoto included in the Natura area are located around one kilometre northwest of the project area. The Natura area includes the Liiklankari forest area in the southern part of Olkiluoto Island (site 5).
3. A large part of the Natura area located south and southwest of Olkiluoto is included in the Raumanmeri nature and hiking area (site 8) and the Laukkari nature reserve (site 11). The northern part of the Natura area belongs to the Bothnian Sea National Park (site 4). The Natura area covers most of the beach areas included in the Rauma archipelago coastal protection programme (site 3). Almost the entire Natura area is included in the IBA and FINIBA bird areas (site 1).
4. Rauma archipelago coastal protection programme area (RSO020020). Most of the area is included in the Rauma archipelago Natura area (site 2).
5. Bothnian Sea National Park (KPU020037). The National Park was established by law (326/2011) for the protection and management of the underwater nature, archipelagos and islets, coastal wetlands and related species of the Bothnian Sea, the conservation of natural and cultural heritage, and general nature recreation, education and research, as well as monitoring of environmental change. The national park includes approximately 91,200 hectares of land and water. As a separate small area, the national park includes a small body of water to the west of Kornamaa Island north of Olkiluoto.
6. Liiklankari Nature Reserve (VMA020001). The Liiklankari nature reserve (57.5 ha) in the southern part of Olkiluoto is included in the national old-growth forest protection programme (AMO020001) and the Rauma archipelago Natura area (site 2).
7. Kääntentila Nature Reserve (YSA239598). A nature reserve (19.4 ha) located south of Olkiluoto in Kivi-Reksaari.
8. Ympyriäinen Nature Reserve (YSA239819). A nature reserve (22.2 ha) located south of Olkiluoto on Ympyriäinenmaa Island. It covers most of the island, with the exception of built-up beach areas.
9. Raumanmeri Nature and Hiking Area (YSA236619). Established in 2016, the nature reserve covers approximately 1,100 hectares and includes a significant part of the Rauma archipelago, bordering the Bothnian Sea National Park. Among other things, the area includes significant parts of the islands of Reksaari, Omenapuu and Nurmes, which have value in terms of nature conservation and cultural history. From Nurmes Island, included is the Mustanperä site of the old-growth forest protection programme (AMO020321). Parts of the area are included in the Rauma archipelago Natura area (site 2) and the coastal protection programme area (site 3).

10. Kornamaa old-growth forest protection programme site (AMO000093). Small forest area located near the northern shore of Olkiluoto in the western part of Kornamaa Island.

11. Kuivalahti FINIBA area (1,026 ha). One of Finland's important FINIBA bird areas, Kuivalahti is a diverse coastal area that rapidly changes from a shallow open-sea shoreline to a sheltered cove and extensive flads (Leivo et al. 2002).

12. Laukkari Nature Reserve (YSA024635). A two-part nature reserve (118.6 ha) southwest of Olkiluoto in the northern part of Aikonmaa Island. Almost all of the area is included in the Rauma archipelago Natura area (site 2).

13. Vasikkakari Nature Reserve (YSA239926). A small nature reserve (1.5 ha) located south of Olkiluoto in the southern part of Ympyriäinenmaa Island.

14. Mäntyrinne Nature Reserve (YSA206416). A nature reserve (6.0 ha) located south of Olkiluoto on Taipalinenmaa Island.

15. Eurajoki estuary FINIBA area (1,605 ha). The Eurajoki estuary, one of Finland's important FINIBA bird areas, is a diverse estuary containing wetlands, agglomerations, fields and coastal groves (Leivo et al. 2002). The area is located east of Olkiluoto.

16. .Vähämaa Nature Reserve (YSA239599). A two-part nature reserve (12.4 ha) on the Taipalmaa peninsula, approximately five kilometres south of Olkiluoto.

Table 1. Natura 2000 areas (green), nature reserves (yellow) and other nationally valuable nature sites (white) at a distance of around 5 km from the site of the Olkiluoto power plant.

Number	Location	Description
1	Rauma-Luvia (-Pori) archipelagos	IBA area and FINIBA area
2	Rauma archipelago	Natura 2000 area
3	Rauma archipelago	Coastal protection programme area
4	Bothnian Sea National Park	National Park
5	Liiklankari Nature Reserve	Nature reserve, old-growth forest protection programme area, included in the Rauma archipelago Natura area
6	Kääntentila Nature Reserve	Nature reserve
7	Ympyriäinen Nature reserve	Nature reserve
8	Raumanmeri Nature and Hiking Area	Nature reserve
9	Kornamaa	Old-growth forest protection programme area
10	Kuivalahti	FINIBA area
11	Laukkari Nature Reserve	Nature reserve
12	Vasikkakari Nature Reserve	Nature reserve
13	Mäntyrinne	Nature reserve
14	Eurajoki estuary	FINIBA area
15	Vähämaa Nature Reserve	Nature reserve

3.7 BOTHNIAN SEA NATIONAL PARK

The Bothnian Sea National Park extends from Merikarvia to Kustavi. The main purpose of the national park is to protect the underwater nature and ecosystems of the coastal zone of the Bothnian Sea and to keep the fish stock viable. The Bothnian Sea National Park does not extend into the Posiva final disposal area (Figure 16).

The Act on the Bothnian Sea National Park was approved by the Finnish Parliament on 8 March 2011, with the area limitations presented in the legislation proposal. The Environment Committee amended the Act with the following section: *"Conducting cooling water from a nuclear power plant. Notwithstanding the declarations of game preservation, activities required for the remote intake and discharge of cooling water from the Olkiluoto nuclear power plant may be performed in the area of the Bothnian Sea National Park, subject to permission from Metsähallitus."*

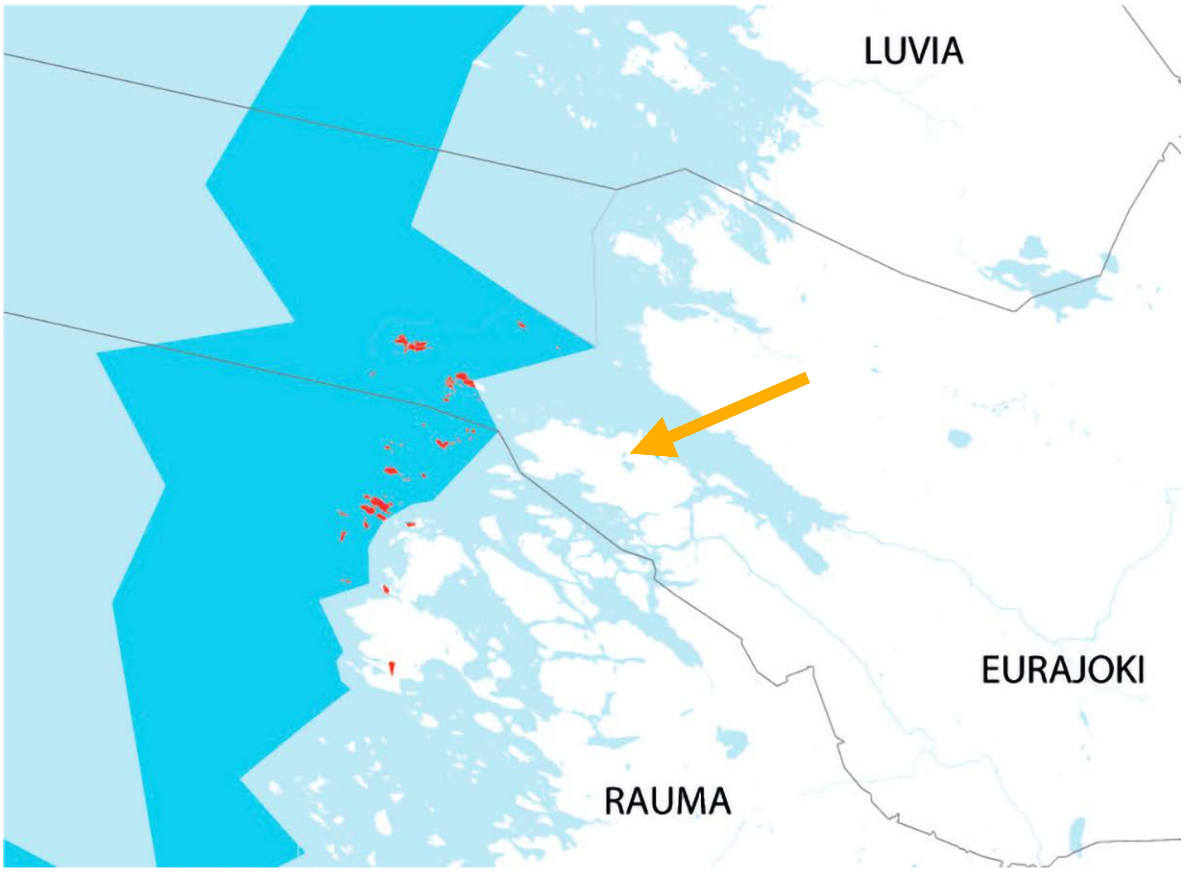


Figure 16. Location of the Bothnian Sea National Park in front of Olkiluoto.

04

REPORT ON THE ORGANISATION OF
NUCLEAR WASTE MANAGEMENT

■ **Photo:** Posiva Oy

TABLE OF CONTENTS

1. BACKGROUND; TIMETABLES OF NUCLEAR WASTE MANAGEMENT

This is a description of the nature and maximum amount of nuclear materials or nuclear waste manufactured, produced, processed, used or stored at the nuclear facility and a description of the applicant's plans and available methods for arranging the management of nuclear waste including the dismantlement of the nuclear facility and final disposal of nuclear waste, and a description of the timetable of nuclear waste management and its estimated costs.

The Radiation and Nuclear Safety Authority Regulation on the Safety of a Nuclear Power Plant (Y/1/2018, Section 13) and the Radiation and Nuclear Safety Authority Regulation on the Safety of Disposal of Nuclear Waste (Y/4/2018) contain provisions regarding the processing, storage and final disposal of radioactive waste. Financial provision for the costs of nuclear waste management is subject to the Nuclear Energy Act (Nuclear Energy Act 990/1987, Chapter 7). According to the Nuclear Energy Act, the party with a waste management obligation shall present a plan concerning the implementation of nuclear waste management every three years. Together with Posiva, the parties with a waste management obligation, TVO and Fortum, have updated the nuclear waste management programme (YJH) the last time in autumn 2021 (YJH-2021). A summary of the schedule for nuclear waste management is presented in Figure 1.

The outset for the requirements for nuclear waste management is ensuring safety by isolating the waste from living nature. The final disposal of nuclear waste is planned such that the safety of the disposal does not require supervision.

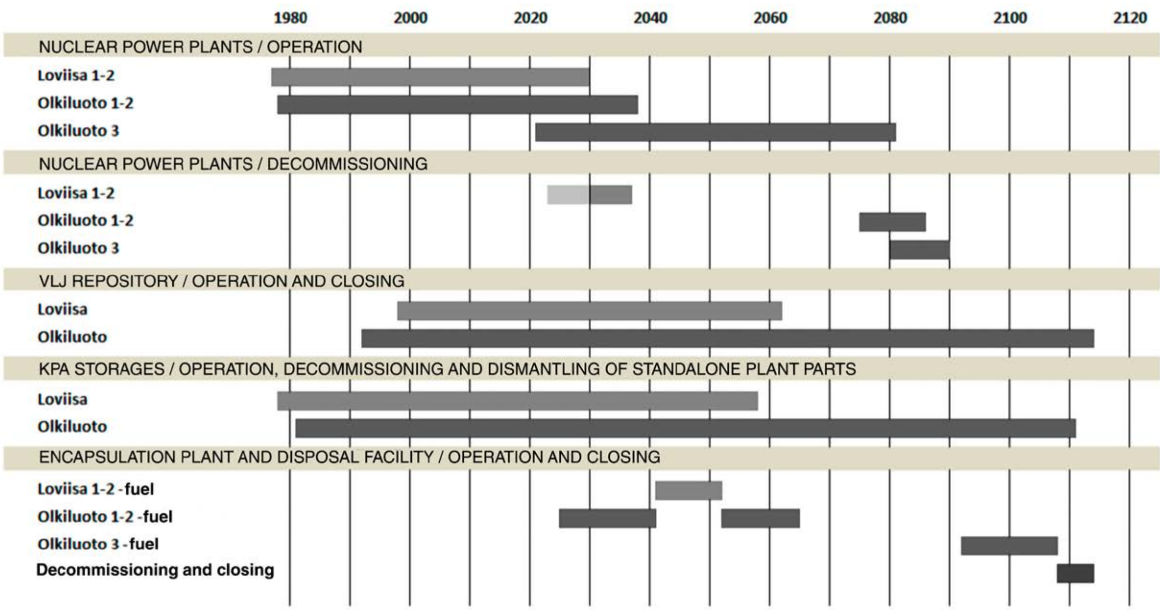


Figure 1. Schedule for the implementation of nuclear waste management according to the YJH-2021 programme. According to the current plans, the nuclear waste management measures will end in approximately one hundred years.

2. PRINCIPLES OF NUCLEAR WASTE MANAGEMENT - TVO TAKES CARE OF THE OPERATING WASTE GENERATED AT POSIVA

In February 2021, Posiva submitted its plans on the principles of nuclear waste management to the Ministry of Economic Affairs and Employment. The Ministry approved the principles in September 2021. According to the principles, Posiva will transfer the waste management obligation concerning the processing, storage and final disposal of the low and intermediate-level nuclear waste generated at the encapsulation plant (operating waste), as well as its possible clearance from regulatory control, to Teollisuuden Voima Oyj (TVO). The waste management obligation concerning the decommissioning waste for Posiva's nuclear facilities will remain with Posiva. The amount of Posiva's operating waste will be very small compared to the operating waste from the Olkiluoto nuclear power plant units. TVO has more than 40 years of experience in nuclear waste management. Since Posiva's encapsulation plant is located in the same Olkiluoto power plant area, its operating waste can be transferred to the Olkiluoto nuclear facilities' processing and storage locations over a short distance.

3. GENERAL INFORMATION ABOUT POSIVA'S NUCLEAR WASTE MANAGEMENT

Posiva Oy's (Posiva) facility complex comprises two nuclear facilities: an encapsulation plant and a disposal facility. At the encapsulation plant, spent nuclear fuel is encapsulated in final disposal canisters. The final disposal canisters are taken from the encapsulation plant to the disposal facility, which comprises underground disposal repository premises and central tunnels that connect them as well as other underground and overground auxiliary facilities and technical facilities.

New radioactive materials are not generated as a result of the encapsulation plant's normal operation. Rather, all the radioactivity that occurs at the plant comes from the spent nuclear fuel to be placed in final disposal. Nuclear facility waste is only generated when the encapsulation plant is being operated and, even then, their quantity and space requirement are quite low. No radioactive waste is generated elsewhere in Posiva's nuclear facilities.

There are three main phases in the arrangement of nuclear waste management: waste processing, interim storage and final disposal. The processing and interim storage phases for both spent fuel and nuclear facility waste are safely under way in the Olkiluoto power plant area. Measures have been taken for reducing the amount of waste, and this can also be done outside of the power plant area through separate licencing.

Posiva will not itself carry out the processing and interim storage of nuclear facility waste. Rather, Posiva will transfer the waste management obligation to TVO, which has in place the practices and systems for the processing and storage of nuclear facility waste. Since TVO's nuclear power plant is located in the same area, Posiva has no reason to build similar processing and storage capabilities for itself. However, Posiva's encapsulation plant has premises that can be assigned for this use later on, if it becomes necessary. As the annual waste volumes from the encapsulation plant are very low, the waste can be placed in interim storage at the encapsulation plant.

Before Posiva generates any operating waste, the operating licence conditions of the Olkiluoto operating waste repository (VLJ cave) will be amended in order to enable the final disposal of Posiva's waste in the VLJ cave. Posiva's nuclear facility waste was already considered in the VLJ cave's periodic safety review for 2021, according to which their final disposal is safe. The licence is currently valid until the end of 2051.

In its operating licence application, Posiva is also applying for a licence for its own disposal repository for low and intermediate-level waste. This disposal repository would be tentatively located along the ONKALO® driving tunnel at a depth of approximately 180 m (Figure 2). It is estimated that the implementation of this facility will only be relevant after several decades. The intention is to use this facility for the final disposal of operating and decommissioning waste from Posiva's nuclear facilities and, as necessary, nuclear waste and other radioactive waste from Olkiluoto. All of the waste management phases for the waste accumulated during decommissioning will only become relevant after several decades.

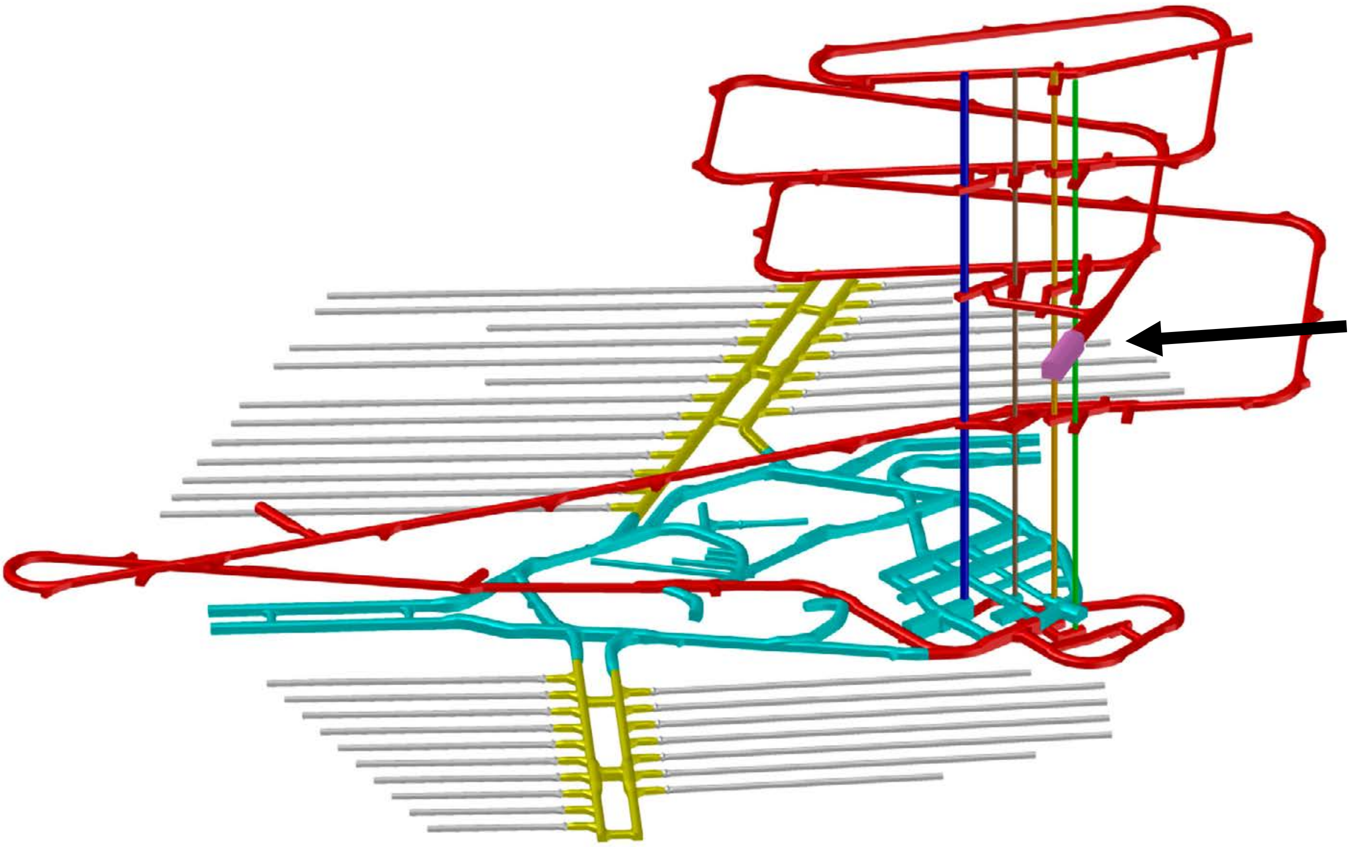


Figure 2. The allocation for a disposal repository for low and intermediate-level waste (purple section) indicated in the figure with an arrow; this facility would be located at a depth of approximately 180 m. The red section is the Onkalo driving tunnel. The other sections pictured belong to the spent nuclear fuel disposal repository, which is located at a depth of approximately 430 m.

4. NUCLEAR FACILITY WASTE GENERATED AT THE ENCAPSULATION PLANT

Nuclear material refers to special fissionable materials and source materials, such as uranium, thorium and plutonium, which are suitable for producing nuclear energy. At Posiva's nuclear facilities, these materials are only relevant in relation to the spent nuclear fuel.

According to the Nuclear Energy Act, nuclear waste refers to

a) *radioactive waste in the form of spent nuclear fuel or in some other form, generated in connection with or as a result of the use of nuclear energy; and*

b) *materials, objects and structures which, having become radioactive in connection with or as a result of the use of nuclear energy and having been removed from use, require special measures because of the danger arising from their radioactivity.*

The radioactive waste generated during the operation of the encapsulation plant is the result of radioactive substances being released from the spent fuel, of which a small portion travels to the operating and decommissioning waste in connection with the plant's service and cleaning work.

Nuclear waste from the plant is divided into two main categories:

1. operating phase waste accumulated during the operation of the plant; and
2. decommissioning waste generated during decommissioning.

At the encapsulation plant, radioactive waste is mainly generated in the fuel handling cell, the decontamination centre and the transfer corridor of the transport container, if the surface of the container is contaminated and contaminates come off. In the handling cell, solid waste from the fuel (activated corrosion products as well as any pieces of fuel) is collected and placed in final disposal together with the fuel elements.

Low-level liquid waste is mainly generated in the washing of the handling cell's steel lining, drying of fuel, washing of the decontamination centre and the solutions used in the decontamination centre. Furthermore, small amounts are possibly generated during the transport container cleaning. Water collected by floor drainage in the radiation controlled area is classified as low-level waste, unless measurements can show that the water is clean. Water that has been found to be clean can be led to the drainage system of the plant area. Final disposal of all radioactive waste takes place in solid form. According to the current plan, liquid radioactive waste is to be processed at the Olkiluoto 3 plant unit. Nuclear facility waste is to be processed at the facilities located in the Olkiluoto nuclear power plant area with the methods considered to be the most appropriate.

Equipment and machines removed from the handling cell for replacement are low or intermediate-level waste. The equipment to be removed will be decontaminated at the decontamination centre before their possible repair at the active workshop. If the equipment cannot be repaired, it is decontaminated and cleared from regulatory control or packed and delivered to the disposal repository. The controlled area and fuel handling cell ventilation filters, as well as the vacuum system filters, are packed and delivered to the disposal repository.

Any radioactive organic waste generated during operation (including protective and cleaning equipment) are packed and compressed in order to reduce their volume before placement in final disposal. It may be necessary to reject some copper canisters if the lid weld seam does not meet the set quality requirements. In this case, the fuel is removed from the canister and moved to another canister. If the insert of a rejected canister cannot be cleaned of radioactivity, it is placed in final disposal as a whole unit. The canister's copper and steel lids and copper shell are removed from around the insert and delivered to be recycled if no radioactivity is detected in the materials.

This appendix provides an account of the nature and accumulated amounts of nuclear materials and nuclear facility waste being generated, processed, used or stored at the encapsulation plant and disposal facility. Furthermore, this appendix describes the process of spent nuclear fuel travelling from interim storage at nuclear power plants to the encapsulation plant and further to final disposal. Furthermore, it explains what kind of nuclear waste may be generated in connection with the processing of fuel, the possible amounts of such waste as well as the collection, processing, storage and final disposal of the waste.

This assessment does not cover the interim storages of spent nuclear fuel in Olkiluoto and Loviisa. Moreover, transports and transfers from the interim storages are subject to different licences than the operation of the encapsulation plant or disposal facility.

The intention is to process and store the nuclear facility waste generated during final disposal operations by using the storages and systems located in the Olkiluoto nuclear power plant area. The encapsulation plant includes allocations for premises in order to arrange independent processing of nuclear facility waste, if necessary. The amounts of decommissioning waste and nuclear facility waste accumulated at the encapsulation plant and disposal facility have been estimated in mode detail on the basis of the information provided in the final safety analysis report and its topical reports submitted to STUK.

Nuclear facility waste is service waste and other waste generated during the operation of the encapsulation plant and disposal facility that cannot be cleared from regulatory control due to their radioactivity. This nuclear facility waste is divided into very low, low and intermediate-level waste. At Olkiluoto, there are dedicated effective and safe processing, storage and final disposal processes for all nuclear facility waste.

Spent nuclear fuel is high-level nuclear waste. The purpose of Posiva's encapsulation plant and disposal facility is the safe final disposal of spent nuclear fuel at the disposal facility. The encapsulation plant and disposal facility does not process fresh nuclear fuel. Were components that have become radioactive in the vicinity of the reactor to be disposed of at Posiva's facilities, separate plans based on a safe final disposal solution would be drawn up.

The amounts of nuclear material and nuclear waste presented in this appendix are based on a 60-year service life for the Olkiluoto 1, 2 and 3 (OL1, OL2, OL3) plant units and a 50-year service life for the Loviisa 1 and 2 (LO1, LO2) plant units. Any change in the service life of these plants will affect the amount of accumulated nuclear material and nuclear waste.

5 NUCLEAR MATERIALS AND NUCLEAR WASTE RELATING TO THE FINAL DISPOSAL OPERATIONS

5.1 SPENT FUEL

As a result of nuclear reactions, new elements and radioactive isotopes have formed in the fuel elements that are removed from the reactors. Part of the uranium in the spent fuel has been converted into fission products, plutonium and a small amount of other actinides. Depending on the degree of fuel enrichment, spent fuel contains 94–96% of uranium, 3–5% of fission products and approximately 1% of plutonium and other actinides.

Due to its radioactivity, the spent fuel generates heat upon removal from the reactor. The radioactivity and heat generation of the fuel depend on the burn-up. The radioactivity and heat generation of the spent fuel are reduced after removal from the reactor.

Below is an example of the radioactivity and heat generation calculated for the fuel of the OL1/OL2 plant units at different cooling times, with a fuel burn-up of 50 MWd/kgU, a gap history of 40% and a 3.8% concentration of ^{235}U in the uranium of fresh fuel.

After spent nuclear fuel has been sufficiently cooled in interim storage, its final disposal can be started. At this point, the radioactivity and heat generation of the spent nuclear fuel will have reduced to approximately one thousandth compared with the time of removal from the reactor.

The spent fuel elements removed from the reactor are stored in pools of water. Initially, the storage takes place in the power plant units' fuel pools. Some of these elements can still be used by placing them back inside the reactor. After the fuel elements have cooled for approximately 5 years in the pools, they are taken inside a transfer cask to the pools in the spent fuel interim storage (KPA storage). After several decades of cooling, the spent nuclear fuel is transported from the KPA storage to Posiva's facilities for encapsulation and final disposal.

A total of 8,155 fuel assemblies had been transferred to the KPA storage at Olkiluoto by 13 September 2021. According to nuclear material accounting, at this time, the spent fuel at the Olkiluoto 1 plant unit contained approximately 130 tonnes of uranium, of which U-235 amounted to approximately 0.8 tonnes and plutonium to approximately 1.3 tonnes. The KPA storage had approximately 1,400 tonnes of uranium, of which U-235 amounted to approximately 10 tonnes and plutonium to approximately 12 tonnes. At the same time, the Olkiluoto 2 plant unit had approximately 130 tonnes of uranium, of which U-235 amounted to approximately 0.75 tonnes and plutonium to approximately 1.2 tonnes. The accumulated amounts of thorium are clearly lower, and no record is being kept of them. Both plant units have been estimated to generate a total of 14,056 assemblies of spent fuel during their 60-year service life, corresponding to approximately 2,500 tonnes of uranium. For fresh fuel, the number of assemblies at OL1 and OL2 is 600 assemblies and the amount of uranium is approximately 100 tonnes per plant unit.

Cooling time	Radioactivity	Heat generation
0 yrs	6,360 TBq/kgU	1,720 W/kgU
1 yr	98 TBq/kgU	11 W/kgU
10 yrs	20 TBq/kgU	1.8 W/kgU
100 yrs	2.1 TBq/kgU	0.4 W/kgU
1,000 yrs	0.07 TBq/kgU	0.06 W/kgU
10,000 yrs	0.02 TBq/kgU	0.01 W/kgU
100,000 yrs	0.003 TBq/kgU	0.001 W/kgU
1,000,000 yrs	0.001 TBq/kgU	0.0004 W/kgU

For Loviisa, the status on 25 August 2021 is as follows: the KPA storage has approximately 5,500 assemblies. There are 503 spent fuel assemblies at the LO1 plant unit and 540 spent fuel assemblies at LO2. The total amount of fresh fuel is approximately 340 assemblies. The amount of uranium in the spent fuel is approximately 62 tonnes at LO1, 66 tonnes at LO2 and 625 tonnes at the KPA storage, with the amount of U-235 being approximately 2 tonnes per plant unit and approximately 7 tonnes at the KPA storage. For fresh fuel, there are some 42 tonnes of uranium, with approximately 2 tonnes of U-235. Both plant units have been estimated to generate a total of 7,700 assemblies of spent fuel (assuming that their service life is not extended and rounded up to the nearest 100 assemblies), corresponding to approximately 795 tonnes of uranium.

5.2 ENCAPSULATION PLANT

In normal conditions, fuel is processed at the encapsulation plant as whole fuel elements. In rare exceptions, fuel may be processed as individual rods that have been removed from fuel elements mostly due to rods becoming damaged (in general, rod damage will also lead to a fuel failure). These rods are placed in rod magazines that can be handled like fuel elements. Rod magazines are similar to fuel elements and their capacity for damaged rods ranges from a few to more than 20 depending on whether it is necessary to include the surrounding rod capsule with the rod that is placed into a rod magazine. There are very few damaged fuel rods, and this rare scenario can be presented such that all the damaged rods can be placed into a few rod magazines. In final disposal production, the encapsulation and final disposal of rod magazines will be accurately scheduled, and these events will include additional reviews, for example regarding criticality safety and long-term safety.

The amount of spent fuel is described as the weight of the unirradiated uranium it has contained, even though some of the uranium in the spent fuel has become converted to other elements and their isotopes and radioactive substances continuously undergo slow spontaneous fission.

The amount of uranium in a fuel assembly varies between fuel types depending on the nuclear power plant type in which the assembly was used but also between the different designs of the same type of fuel.

The maximum weights of fresh uranium contained in fuel elements are: 186 kgU for BWR (OL1, OL2), 130 kgU for VVER (LO1, LO2) and 545 kgU for PWR (OL3) (the weights include the possible future weight increases). As there are 12 BWR or VVER fuel elements or 4 PWR fuel elements allocated per canister, the average amount of uranium in the final disposal canisters with different fuel types is 2,100 kgU for BWR, 1,464 kgU for VVER and 2,128 kgU for PWR.

The degree of enrichment (concentration of uranium-235 as a percentage) varies significantly between the fuel rods in a fuel element. Furthermore, enrichment and burn-up (which often uses the unit MWd/kgU) have increased over the years. The degree of enrichment does not vary significantly between the different fuel types.

Transfers and transports of fuel from power plant sites to the encapsulation plant use transfer casks and transport containers (a transfer cask is used for internal transfers within Olkiluoto and a transport container is used for transports from the Loviisa nuclear power plant) which allow for transportation of some multiple of fuel elements appropriate for a canister. The fuel elements to be placed in disposal are selected for each canister before transportation, taking into account decay heat generation, level of radiation and reactivity such that the canister's heat generation and criticality safety are at the required level and the radiation dose rate outside the canister remains sufficiently low. This selection process is guided by a purpose-built fuel database. Transport containers that are suitable for the nuclear fuel from each plant type will be obtained. Olkiluoto's own transfer cask is used for internal transfers within Olkiluoto.

The uranium amounts of typical individual transport containers would be, at most, as follows, calculated at the maximum fuel element uranium weights:

- Castor TVO, 41 BWR fuel elements, 7,626 kgU
- Castor VVER 440/84, 84 VVER fuel elements, 10,920 kgU
- Planned PWR transport container, 12 PWR fuel elements, 6,540 kgU.

Table 1 presents the planned maximum amounts of spent fuel possibly located in the different sections of the encapsulation plant. It is not the intention to store any more fuel in the encapsulation plant than it is necessary for the flexible conduct of the operations. Small storage amounts might be accumulated in the reception facility if, for example, Loviisa fuel is transported by sea, in which case it is appropriate to transfer more than one transport container at the same time. The calculations make preparations for the storage of a maximum of 4 transport containers in the reception facility.

5.3 DISPOSAL FACILITY

Fuel is transferred to the disposal facility one canister at a time and, depending on the encapsulation rate, 0–100 canisters annually. At the final disposal level, near the bottom end of the canister shaft is the buffer storage for canisters to be placed in final disposal, which is dimensioned for a maximum of 30 canisters. This amount is appropriate in order to ensure that, at the beginning of the campaign, in the canister storages of the encapsulation plant and disposal facility there are loaded and inspected final disposal canisters in the amount equivalent to the final disposal in one deposition tunnel. This way, the final disposal operations regarding a single tunnel can proceed as quickly as possible and the tunnel backfilling can be completed without disturbances. When preparing for the final disposal of the fuel accumulated during the planned service life of the OL1–3 and LO1–2 plant units and the fuel currently located at the plants, the plans are made for the final disposal of a maximum of 6,500 tU of fuel, which corresponds to approximately 3,300 canisters. This is the maximum amount according to the construction licence. Table 2 presents a more detailed assessment of the different plant units' fuels. Approximately 15% of the PWR fuel assemblies are assumed to also include the control elements. The average burn-up is approximately 40 MWd/kgU for OL1–2 and LO1–2 and 45 MWd/kgU for OL3.

Furthermore, at Olkiluoto Island, preparations have been made for the final disposal of the operating and decommissioning waste from the encapsulation plant in disposal facilities with a total volume of approximately 1,500 m^3 and radioactivity of approximately 550 GBq.

Table 1a. Maximum amounts of spent fuel in the different sections of the encapsulation plant. In normal conditions, there is only a fraction of the maximum amounts of spent nuclear fuel in the encapsulation plant.

Plant section	Amount (kgU)	Description
Reception facility	4 x 10,500	4 transport containers
Transport container transfer corridor	10,500	1 transport container
Handling cell	2,200	Batch equivalent to 1 canister
Canister transfer corridor	2,200	1 canister
Canister buffer storage at the encapsulation plant	12 x 2,200	12 canisters
Transfer route to the disposal facility	2,200	1 canister
Total	**85,500**	**Total maximum amount**

Table 1b. Allocations included in the final disposal plan for the accrued fuel amounts of the different plant units and the estimated average discharge burn-up.

	OL1–2	OL3	LO1–2	Total
Fuel (tU)	2,904	2,500	1,096	**6,500**
Canisters	1,383	1,175	746	**3,304**

5.4 PROCESSING OF SPENT NUCLEAR FUEL

Before spent nuclear fuel is placed in final disposal, the nuclear fuel removed from the reactor is cooled sufficiently so that it becomes suitable for final disposal in terms of its decay heat power and level of radiation. Spent fuel is chosen for final disposal based on a fuel database, which is used for determining the fuel to be placed in the final disposal canisters.

5.4.1 STORAGE AT THE NUCLEAR POWER PLANT

After its removal from the reactor, spent fuel is typically stored for 3–5 years in water pools located in the reactor building. The water cools the nuclear fuel and protects the environment from the radiation emitted by the fuel. The fuel pools are separate and located on the different sides of the reactor, which allows for isolating individual pools from each other and the reactor pool in the event of a possible evacuation scenario.

In addition to irradiated fuel assemblies, the fuel racks in the pools are used for storing fresh fuel assemblies, dummy elements, rod magazines and radiating operating waste placed in separate transport shields.

During operation, preparations have been made for the emptying of any pool when necessary by moving the fuel assemblies inside it into the other pools in the plant area.

5.4.2 TRANSFERS AND TRANSPORTS OF FUEL FROM THE KPA STORAGES TO THE ENCAPSULATION PLANT

Moving spent nuclear fuel within Olkiluoto from the KPA storage to the encapsulation plant is referred to as a "transfer" and moving spent nuclear fuel from the Loviisa KPA storage to the encapsulation plant, which is currently scheduled to begin in the 2040s, is referred to as a "transport".

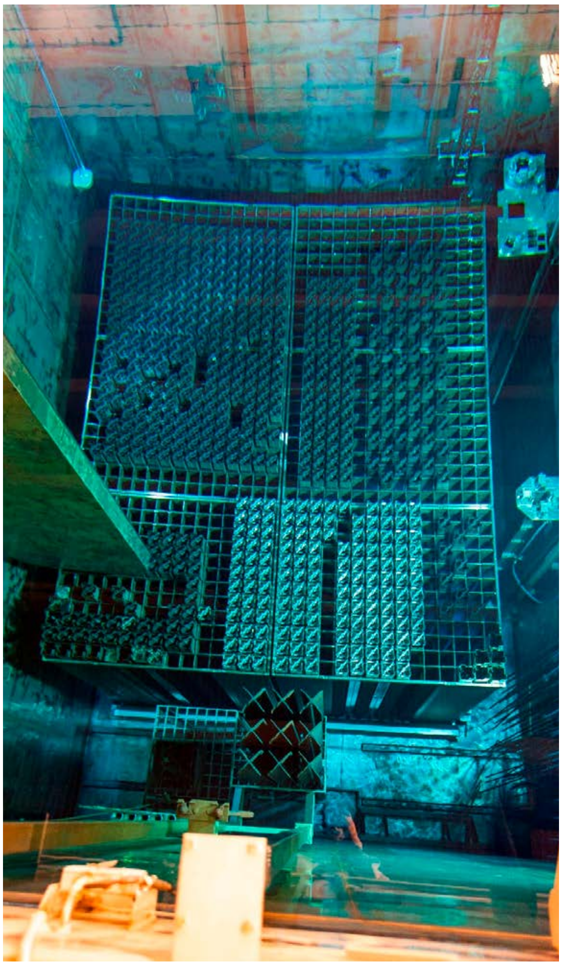


Figure 3. Nuclear fuel is always processed in a safe manner.

Spent nuclear fuel is transferred from the Olkiluoto KPA storage to the encapsulation plant by using TVO's transfer cask as a wet transport. The transfer cask is transported in horizontal position from the KPA storage to the encapsulation plant as a protected internal transfer within the plant area. The requirements set by nuclear and radiation safety are considered when planning the filling of the transfer cask. The transfer cask is sealed at the KPA storage in accordance with nuclear safeguards requirements.

Fuel transports from the Loviisa nuclear power plant to the encapsulation plant are described in the appendix "Analysis of the risks related to the transport of spent nuclear fuel" to the operating licence application. As separate licences according to the Nuclear Energy Act will be obtained for the transports, the current plan is to continue the selection of mode of transport and transport routes and detailed planning in the 2030s. As the transports from Loviisa will begin at a later time, the final disposal of the OL1 and OL2 fuel will provide experience in the smoothness of Posiva's production operations and in the reception of transports at the encapsulation plant before the transports from Loviisa are planned and started. Furthermore, the schedule for the final disposal of fuel from Loviisa will be confirmed only after a few years of final disposal operations.

5.4.3 ENCAPSULATION AND FINAL DISPOSAL OF SPENT FUEL

Spent fuel is transferred from the KPA storages to the encapsulation plant for encapsulation, where the fuel is packed inside a final disposal canister made of copper and cast iron. After the encapsulation, the canisters are transferred individually to the disposal facility located at a depth of approximately 430 metres and placed in dedicated deposition holes inside a deposition tunnel. After the tunnel is full, it is closed with a plug, which concludes the final disposal of the spent nuclear fuel. Once all of the spent fuel has been placed in final disposal, the closure of the encapsulation plant (decommissioning) begins, the other premises of the disposal facility are filled and the facility is closed. A technical description of the final disposal operations is presented in Appendix 5 to this operating licence application.

6 CONCEPT OF SAFE FINAL DISPOSAL

Posiva's final disposal concept is based on the KBS-3 solution developed by SKB in Sweden. The foundation for the concept is the multi-barrier principle, in which the spent fuel is isolated by means of several release barriers that supplement each other. According to the concept, it is unlikely that an individual detrimental phenomenon or uncertainty could lead to the inoperability of the entire system. The primary option chosen for final disposal is the vertical deposition solution KBS-3V. The requirement for the design and construction of all the engineered release barriers is that they must not significantly reduce the safety functions of the other release barriers (whether constructed or natural). The fuel elements that are brought to the encapsulation plant in transfer casks or transport containers are placed in a final disposal canister in the fuel handling cell. The copper lid of the canister is friction stir welded shut.

Figure 4. Final disposal canisters for the different fuel types: pictured are the canister types for Loviisa 1–2 (VVER 440) on the left, Olkiluoto 1–2 (BWR) in the middle and Olkiluoto 3 (EPR, OL3) on the right.

6.1 NUMBER OF CANISTERS AND DIMENSIONING BASIS

The size of the canister and the shape of the cast-iron insert depend on the fuel placed in final disposal. Figure 4 presents the different canister types for VVER, BWR and EPR fuels. The BWR canister type is intended for the final disposal of spent fuel from the Olkiluoto 1 and 2 plant units. Table 2 includes the main dimensions and weights for different canister types. Table 3 presents the amounts of fuels and final disposal canisters.

6.2 PROCESSING AND STORAGE OF OPERATING WASTE

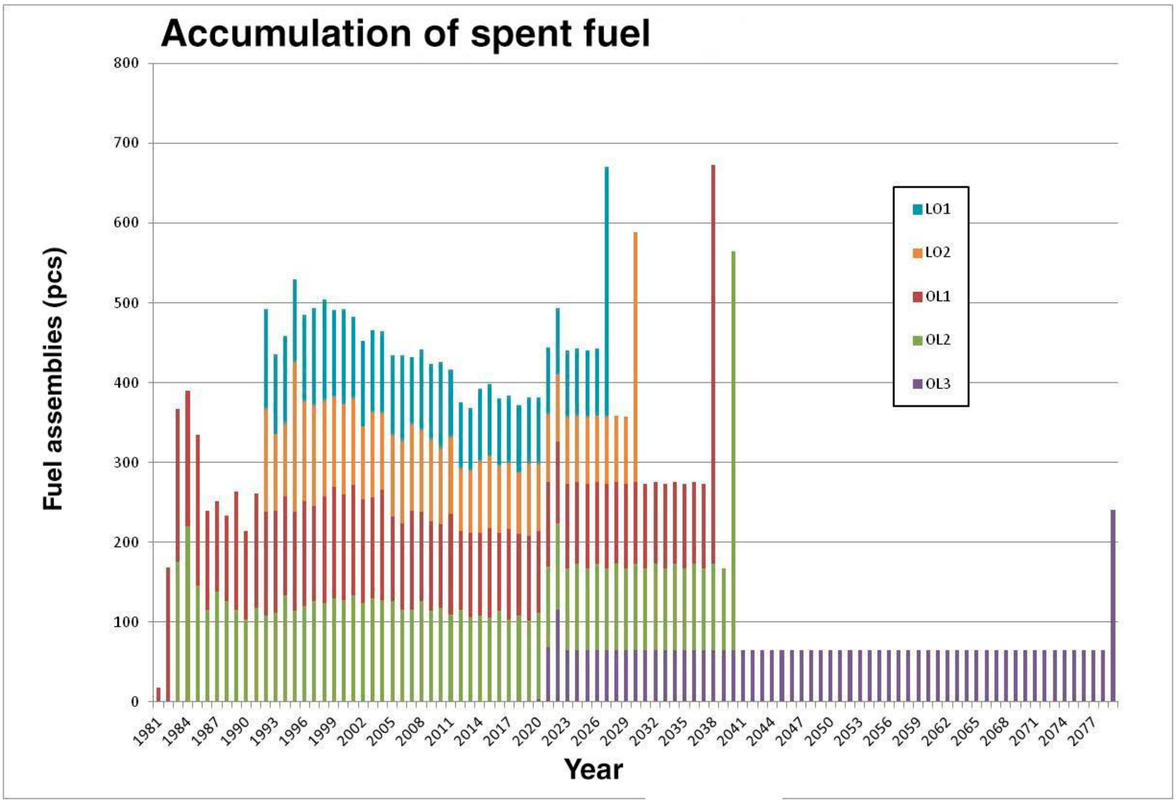
The final disposal of spent nuclear fuel generates low and intermediate-level waste during normal operations only at the encapsulation plant. Posiva

Table 2. Allocations included in the final disposal plan for the accrued fuel amounts of the different plant units and the estimated average discharge burn-up.

Main dimensions	Loviisa 1–2	Olkiluoto 1–2	Olkiluoto 3
Outer diameter (m)	1.05	1.05	1.05
Total length (m)	3.60	4.80	5.25
Total volume (m3)	3.0	4.1	4.5
Assembly positions (pcs)	12	12	4
Amount of fuel (tU)	1.4	2.2	2.1
Total weight (t)	18.6	24.3	29.1

■ **Table 3.** Allocations included in the final disposal plan for the amounts of fuel to be placed in final disposal from the different plant units.

Plant units	Fuel (tU)	Canisters (pcs)
OL1–2	2,904	1,383
LO1–2	1,096	746
OL3	2,500	1,175
Total	**6,500**	**3,304**



■ **Figure 5.** Variation in the number of fuel assemblies per discharge batch between the different Finnish nuclear power plant units based on the current service lives. Planned values are presented from the year 2016 onward, as the start-up of the OL3 plant unit has been delayed from this plan. The size of the final core is 500 assemblies for OL1–2, 313 assemblies for LO1–2 and 241 assemblies for OL3.

transfers the waste management obligation for low and intermediate-level operating waste generated at the encapsulation plant to TVO. The operating waste from the encapsulation plant is processed at TVO's plant units OL1, OL2 and OL3 by using the available systems, taken to interim storage in the MAJ and KAJ storages and placed in final disposal at TVO's VLJ cave or a near-surface final disposal facility planned at Olkiluoto. Some of the operating waste will be cleared from regulatory control after processing. At TVO, the operating waste is entered in waste records according to Guide YVL D.4. A record is kept at the encapsulation plant of the dose rates and amounts of waste stored at the plant. It must be possible to separate the waste from TVO's waste when it is transferred to TVO for processing.

The power plants' waste processing systems will be utilised as long as the power plants remain in operation, i.e. until approximately 2080 according to the current plans. The VLJ cave will also be utilised for as long as the cave is available.

After the closure of the power plants and the VLJ cave, the waste processing functions will take place at the encapsulation plant, and preparations will be made for placing operating and decommissioning waste in final disposal at a disposal repository for low and intermediate-level

Table 4. Amounts of operating and decommissioning waste generated at the encapsulation plant after processing and packing. The amounts are based on the final disposal of 6,500 tU of spent nuclear fuel.

Encapsulation plant	Solid (m^3)	Liquid (m^3)
Operating waste	518	3
Decommissioning waste	119	0.3
Total	**637**	**3.3**

waste to be constructed in connection with the spent nuclear fuel disposal facility at a depth of approximately 180 metres according to tentative plans. Therefore, the design of the encapsulation plant and disposal facility has included space reservations for carrying out waste processing measures and final disposal.

Radioactive operating waste is radioactive liquid and solid waste generated as a result of the encapsulation plant's operation. The radioactivity of the waste comes from spent nuclear fuel.

Radioactive operating waste is divided into the following waste types:

- liquid waste
- dry and solid waste packed in bags or barrels (including service waste and filters)
- scrap metal.

Waste processing at the encapsulation plant includes at least the following functions:

- decontamination of larger components
- waste sorting
- dose rate measurement
- interim storage of waste bags
- transfer of radioactive liquid waste into a transport container
- possible clearance from regulatory control will occur in connection with the processing taking place at the encapsulation plant or the OL1–3 plant units' waste processing facilities.

The encapsulation plant does not have the spaces for long-term interim storage of waste. Instead, after sorting, the waste is taken via a small buffer storage to the OL1–3 plant units' waste processing facilities. The encapsulation plant can store approximately the amount of waste generated over the course of one year. The encapsulation plant has space reservations for independent nuclear waste management, if necessary. The radiation effects from waste processing on the surrounding facilities, systems and functions have been considered in the design of the encapsulation plant.

The estimated amounts of operating and decommissioning waste generated at the encapsulation plant over the course of approximately 100 years are presented in Table 4. The operating waste generated at the encapsulation plant for which TVO takes the waste management obligation is only a fraction of the amount of waste generated at the plant units.

6.3 FINAL DISPOSAL OF OPERATING WASTE

Posiva's operating waste will be placed in final disposal at TVO's operating waste repository (VLJ cave), which is located on the cape of Ulkopää at Olkiluoto. The operating licence conditions of the VLJ cave will be amended in order to also enable the final disposal of Posiva's operating waste. This will be done before the final disposal of Posiva's operating waste becomes relevant. Posiva's operating waste was already considered in the VLJ cave's periodic safety review and, in particular, its safety case in 2021.

There is also a near-surface final disposal repository for very low-level nuclear waste being planned at Olkiluoto. Its licencing also takes into account the potential operating waste coming from Posiva; Posiva's operating waste may, largely, be suitable for near-surface final disposal. Near-surface final disposal is a method widely used around the world, which is being employed in Sweden and France, for example. Near-surface final disposal is subject to an operating permit issued by STUK, which will be applied for in the early 2020s.

In the future, a dedicated disposal repository for low and intermediate-level nuclear waste will be constructed for Posiva. It would be tentatively located along the ONKALO driving tunnel at a depth of approximately 180 m (Figure 2). The needs of the Olkiluoto waste management infrastructure are defined, among other things, by the plant units' decommissioning schedules, so no timetable has yet been determined for the construction of a disposal repository for Posiva's low and intermediate-level nuclear waste. Furthermore, the timetable and need are dependent on the VLJ cave's service life and whether near-surface final disposal is suitable for Posiva's operating waste.

6.3.1 OTHER POSSIBLE LOW AND INTERMEDIATE-LEVEL NUCLEAR WASTE TO BE PLACED IN FINAL DISPOSAL

The disposal repository for Posiva's low and intermediate-level nuclear waste might also be used for the final disposal of used reactor internals, if necessary. Used reactor internals refer to used fuel channels, control rods, core instrumentation, core grid plates and other reactor parts from inside the reactor pressure vessel that have become radioactive due to neutron radiation, with the exception of spent fuel assemblies or parts thereof. Parts with low radioactivity, such as steam separators, are classified as operating waste instead of this waste category. In addition to activation products, fission products and actinides can become attached to the parts' surface mostly as a result of fuel failures. Used reactor internals also include the fuel channels, control rods and core instrumentation inside the reactor at the end of the power plant's operation.

It is estimated that approximately 167 tonnes of used reactor internals are accumulated over the plant units' 60-year service life. The reactor internals accumulated over the course of the plant units' operation are not considered to be actual decommissioning waste. However, they are processed and placed in final disposal mainly with decommissioning waste. Some of these components may have become highly radioactive. In order to reduce the need for interim storage, the intention is to place the least radioactive parts in final disposal together with operating waste. As the plant units' decommissioning plans are specified, it will be planned how and where in the Olkiluoto power plant area these used reactor internals will be placed in final disposal.

7 DECOMMISSIONING OF THE FACILITY

The Nuclear Energy Act (990/1987), the Radiation and Nuclear Safety Authority Regulation on the Safety of Disposal of Nuclear Waste (Y/4/2018) and the YVL Guides, particularly Guides YVL D.4 and D.5, define the goals for nuclear facilities' decommissioning activities in Finland. According to the Nuclear Energy Act, decommissioning is subject to a licence which is applied for separately.

7.1 RADIOACTIVITY INVENTORY OF THE ENCAPSULATION PLANT'S NUCLEAR FACILITY WASTE

The radioactivity of the waste generated during the operation of the encapsulation plant is the result of radioactive substances being released from the spent fuel. Most of the radioactive substances end up in operating waste but a small portion of them may also end up in decommissioning waste through contaminated structures. A small portion of the fuel elements have lost their integrity already at the power plant and a small portion is assumed to become damaged during encapsulation. The amount of fuel that becomes damaged during encapsulation has been estimated based on experience gained at the power plant in fuel transfers.

The estimate on the radioactivity inventory of the waste generated at the encapsulation plant is based on the assumption that up to 87 fuel rods become damaged as a result of operational occurrences and up to 3.6 kg of crud ends up in the encapsulation plant waste. The estimates cover the fuel of the OL1–3 and LO1–2 plant units. The expected value for the operation and decommissioning waste inventory is approximately 53 GBq, but the maximum limit of a conservative estimate is 544 GBq.

8 COSTS OF NUCLEAR WASTE MANAGEMENT AND PROVISION

After the operations of Posiva's encapsulation plant start, its operation will generate some nuclear waste. Furthermore, when the operations end approximately in the 2120s, the decommissioning of the encapsulation plant will also generate waste. The operating waste and decommissioning waste are classified as very low, low or intermediate-level waste. Posiva's nuclear waste management costs result from the management of the aforementioned operating and decommissioning waste and the decommissioning, i.e. closure, of the disposal facility.

8.1 COST ESTIMATE

Before starting operation, Posiva, together with TVO, will apply for the transfer of the waste management obligation for the facility's operating waste to TVO. TVO would then process, store and place in final disposal the facility waste generated during Posiva's operations until further notice as described in Posiva's principles of nuclear waste management that TEM has approved. The costs of the management of Posiva's operating waste are estimated to be approximately EUR 28,000 per year over the course of 58 years of Posiva's operation.

The closure of the disposal facility can be started after operation in the disposal repository area has ended. In practice, this means a situation in which the deposition tunnel is filled and plugged. The closure of the premises will be carried out gradually, for example for the central tunnels of a completed final disposal panel. Once all the panels have been closed, the technical facilities, the rest of the vehicle connections, shafts and the driving tunnel can be closed.

The decommissioning of the encapsulation plant will take place at the same with the final phase of the closure of the disposal facility, which is currently scheduled to occur approximately in the 2120s. In connection with the decommissioning, the radioactive parts and systems of the encapsulation plant are dismantled and packed.

It is estimated that decommissioning and closure will result in other costs as well, including administrative and rental costs.

8.2 PROVISION FOR FUTURE COSTS

Posiva will make provision for the future waste management costs of its facilities in accordance with the Nuclear Energy Act and Decree. The provision arrangements ensure that there are always funds available in the form of reserves or securities for arranging the safe management of all accumulated nuclear waste and decommissioning of the nuclear facilities.

Table 5. Posiva's nuclear waste management cost estimate according to the 2018 total cost estimate (cost level of 2018).

Item	Cost estimate (EUR million)
Final disposal of operating waste	2
Central tunnel backfill	42
Closure of the disposal facility	55
Decommissioning of the encapsulation plant	10
Other costs during decommissioning and closure	24
TOTAL	133
TOTAL including uncertainty allowances (15% for operating waste and central tunnel backfill, 20% for others)	157

In the tentative waste management diagram for 2021, the future costs for Posiva's facilities due to the management of waste accumulated by the end of 2024 and the facilities' decommissioning as well as administrative work and work with authorities are estimated to be approximately EUR 141 million (cost level of 2019, including uncertainty allowances), because the amount of fuel currently considered in the waste management diagram is lower than in the total cost estimate (Table 5).

The waste management diagram is reviewed every three years for the following 3+2 years based on the progress of measures, changes in cost level and possible amendments to plans and cost estimates. The financial provision made by Posiva ensures that the funds required for the safe implementation of nuclear waste management are available.

9 SUMMARY

Posiva's purpose is the final disposal of its owners' spent nuclear fuel. With this application, Posiva is applying for an operating licence for the final disposal of spent nuclear fuel. Posiva has solutions that are considered to be safe for the final disposal of spent fuel and a safety case that ensures long-term safety; these were submitted to STUK as part of the final safety analysis report for the encapsulation plant and disposal facility in connection with this operating licence application. STUK must approve them before an operating licence can be granted.

The waste management obligation for Posiva's operating waste generated as a result of encapsulation will be transferred to TVO, which has in place the practices for managing the operating waste generated during the operations. The waste management obligation of Posiva's own decommissioning waste will remain with Posiva. The practices cover the estimated amounts, processing, interim storage, decommissioning and final disposal of all waste types and clearance from regulatory control. The safety of waste management is assessed in the final safety analysis report and the decommissioning plan.

There are descriptions and schedules for the nuclear waste management measures regarding the different nuclear facilities, and their costs have been estimated. The nuclear waste management measures and schedules are described in detail in the YJH programmes that are published every three years. The most recent YJH programme (YJH-2021) was submitted to the Ministry of Economic Affairs and Employment in autumn 2021. Posiva has in place the nuclear waste management practices and plans, and it has made provision for the costs.

05

A GENERAL DESCRIPTION OF THE TECHNICAL OPERATING PRINCIPLES AND SOLUTIONS AND OTHER ARRANGEMENTS IMPLEMENTED TO ENSURE SAFETY, AS WELL AS A DESCRIPTION OF THE APPLIED SAFETY PRINCIPLES AND AN ASSESSMENT OF THEIR IMPLEMENTATION

Photo: Posiva Oy

CONTENTS

SAFETY OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

A SUMMARY OF THE GENERAL SAFETY PRINCIPLES OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

Posiva Oy's (Posiva) nuclear waste facilities comprise the encapsulation plant and the disposal facility (Figure 1). The design and construction of these facilities have been carried out in compliance with the regulations concerning nuclear and radiation safety. The encapsulation plant is located above the disposal facility. The overground buildings and underground facilities are connected via shafts, which have dedicated lifts for transporting final disposal canisters and personnel to the disposal facility, which is located at a depth of approximately 430 metres. Vehicle traffic to the disposal facility takes place via a driving tunnel. The planning, implementation and operation of the final disposal activities

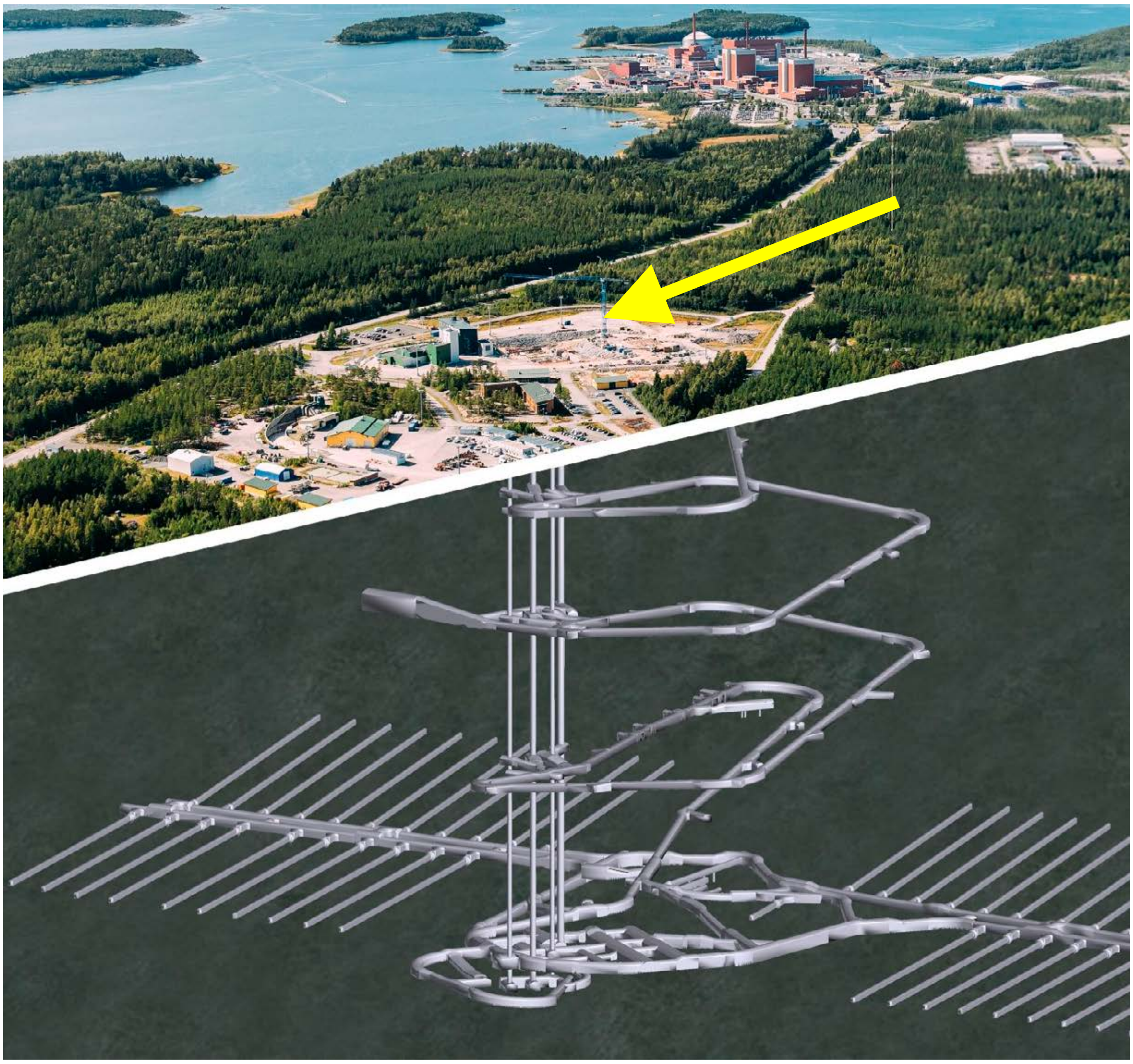


Figure 1. Spent nuclear fuel that has cooled at the interim storage is packed into final disposal canisters at the encapsulation plant. The sealed canister is transferred with a canister lift from the encapsulation plant to the disposal facility, which is located at a depth of approximately 430 metres, where it is placed inside a deposition hole and covered with bentonite. Finally, the tunnels are backfilled and fitted with a plug. The yellow arrow points to the encapsulation plant site (under construction in the figure).

take into account radiation safety in terms of the environment, population and personnel. The safety of final disposal over a span of hundreds of thousands of years has been ensured by conducting long-term safety analyses on the operation of the final disposal system according to national and international requirements and recommendations.

At a time, the encapsulation plant processes a small amount of spent nuclear fuel that has been in interim storage for decades. The radiation level of the cooled nuclear fuel has decreased to approximately one thousandth of the level it had when removed from the reactor. The spent nuclear fuel handling systems at the encapsulation plant have been designed and constructed such that the fuel handling is safe. The spent nuclear fuel is sealed inside final disposal canisters. The fuel elements are placed inside the canister insert, which is designed to provide mechanical protection. The canister's copper shell protects the unit from corrosion. As small amounts of cooled nuclear fuel are processed at one time and the encapsulation plant and its operations are designed to be safe, the risk of a radioactive release is very minor. The safety of personnel in terms of direct radiation from the fuel and low and intermediate-level operating waste generated during the process has been ensured through the use of remote-controlled systems and procedures that minimise the amount of radioactive contamination and the need to work near a radiating object.

The risk of an accident taking place at the encapsulation plant is very low, and an accident would lead to minor consequences. However, should an accident with the worst estimated consequences occur, based on conservative estimates, it would cause, at most, a radiation dose of approximately 2.3 mSv to a resident of the encapsulation plant surroundings. This amounts to approximately half of the specified annual dose limit of 5 mSv. However, the significance of this consequence is reduced by the fact that there is no permanent residence in the surroundings of the plant.

The final disposal canisters are transported to the disposal facility by using a canister lift. It is ensured that the final disposal canisters are free of contamination in order to ensure that no radioactive substances are transported to the disposal facility on the canister surface. Even after spent nuclear fuel has been sealed inside a canister, it radiates so much that the transfers are carried out with remote control. At the disposal facility, the canister is taken into a deposition tunnel and installed inside a hole drilled into the tunnel floor. A buffer made of bentonite clay is installed around the canister in order to limit the amount of water reaching the canister surface. The deposition tunnels are filled with a backfill material and closed with a reinforced concrete plug.

The safety of final disposal has been ensured over very long periods of up to a million years with a long-term safety assessment in compliance with national and international recommendations and requirements (SC-OLA). This analysis comprises several reports, and it has been submitted to the Radiation and Nuclear Safety Authority (STUK) for approval, which is required for obtaining an operating licence. The long-term safety assessment reports are also available on the Posiva website.

The analysis of long-term safety involves assessing how the final disposal canisters will withstand the changing conditions at the disposal facility over the course of thousands of years. Furthermore, the assessment estimates what happens to the nuclear fuel inside the canister if the canister fails as a result of a rare event. The final disposal depth, insolubility of the nuclear fuel, canister insert and copper shell, stable conditions provided by the buffer and slow movements in the deep groundwater provide protection against the effects of radiation.

The analyses consider baseline cases in which everything happens as assumed and the surroundings of the disposal facility develop as expected in the coming millennia. The near-future sea level rises, long-term ice ages, land elevation changes, the changes they cause near the disposal repository and the effects they have on the durability of the final disposal canisters have been considered. Furthermore, large numbers of rarer events and accident scenarios have been analysed. According to the analysis results, long-term safety will be maintained for several hundreds of thousands of years, and even in case of theoretical accidents, the radiation doses will remain low.

THE NUCLEAR WASTE FACILITY MUST DEMONSTRATE COMPLIANCE WITH THE SAFETY REQUIREMENTS

The requirements set for the nuclear and radiation safety of Posiva's nuclear facilities stem from the nuclear energy industry's regulations, including the Nuclear Energy Act, Nuclear Energy Decree and radiation legislation as well as the regulations and guides (YVL Guides) issued by the Radiation and Nuclear Safety Authority (STUK). Furthermore, nuclear facilities are subject to normal industrial requirements, e.g. in terms of construction and industrial safety. As part of TVO Group, Posiva regularly monitors compliance with legislation and other instructions.

As part of the operating licence application documentation, Posiva's assessment of meeting the safety requirements will be submitted to STUK for approval. The purpose of this assessment is to verify that the nuclear industry's regulatory requirements are met at Posiva's nuclear facilities in terms of construction, plant modifications, corporate, safety and preparedness arrangements and the nuclear facilities' operating, radiation and nuclear safety, among other things. Compliance with nuclear safeguards and nuclear waste management requirements is also verified. All in all, the nuclear energy industry's regulations comprise slightly under 8,000 requirements whose fulfilment is estimated.

In the future, compliance with safety requirements must be demonstrated regularly. The operating licence specifies the schedules for the periodic safety assessment. According to the Nuclear Energy Act, nuclear waste facilities must undergo periodic safety assessments at least at 15-year intervals. A periodic safety assessment mainly includes the same content as the operating licence application documentation. However, the safety assessment takes into account the implemented plant modifications, operating experience, safety research results and advances in calculation methods. The periodic safety assessment is submitted to STUK for approval.

AT NUCLEAR WASTE FACILITIES, SAFETY IS ENSURED BY CLASSIFYING THE SYSTEMS ACCORDING TO THEIR SAFETY SIGNIFICANCE

According to Section 5 of the Radiation and Nuclear Safety Authority Regulation on the Safety of Disposal of Nuclear Waste (STUK Y/4/2018), the safety functions and long-term safety functions for the operation of the nuclear waste facility shall be defined, and the systems, structures and components implementing them and related to them shall be classified, while taking into account their purpose, on the basis of their significance in terms of operational safety, long-term safety or both, if necessary. The safety classifications must be used for determining the quality requirements for systems, structures and components.

The safety classifications guide the nuclear facility's design, manufacturing, inspections and approvals at all stages of its service life. Nuclear facilities' safety classification is guided by Guide YVL B.2 issued by the Authority. Among other things, it presents requirements for nuclear facilities' safety and earthquake classification and for the content of the classification document as well as the requirements for the facility's components resulting from the classification during the facility's design, construction and operation. Posiva's safety classification follows Guide YVL B.2.

In terms of long-term safety, more specific information on the classification is provided in Guide YVL D.7 for systems, structures and components that may be significant for the radiation safety of the facility personnel or the prevention or restriction of releases of radioactive substances. Significant functions may include particularly waste packaging transfers, radiation measurements and buffer materials surrounding the waste packaging, backfill and closure structures and the bedrock surrounding the disposal repository. Posiva's safety classifications also take into account the requirements of Guide YVL D.7.

Based on their safety functions, the systems, structures and components receive their classification: Safety Class 1 (SC) is the most demanding while EYT/STUK is the lowest class; in class EYT, the object of classification is not significant in terms of nuclear safety.

The main part of the encapsulation plant comprises the reception room for transport containers and empty final disposal canisters,

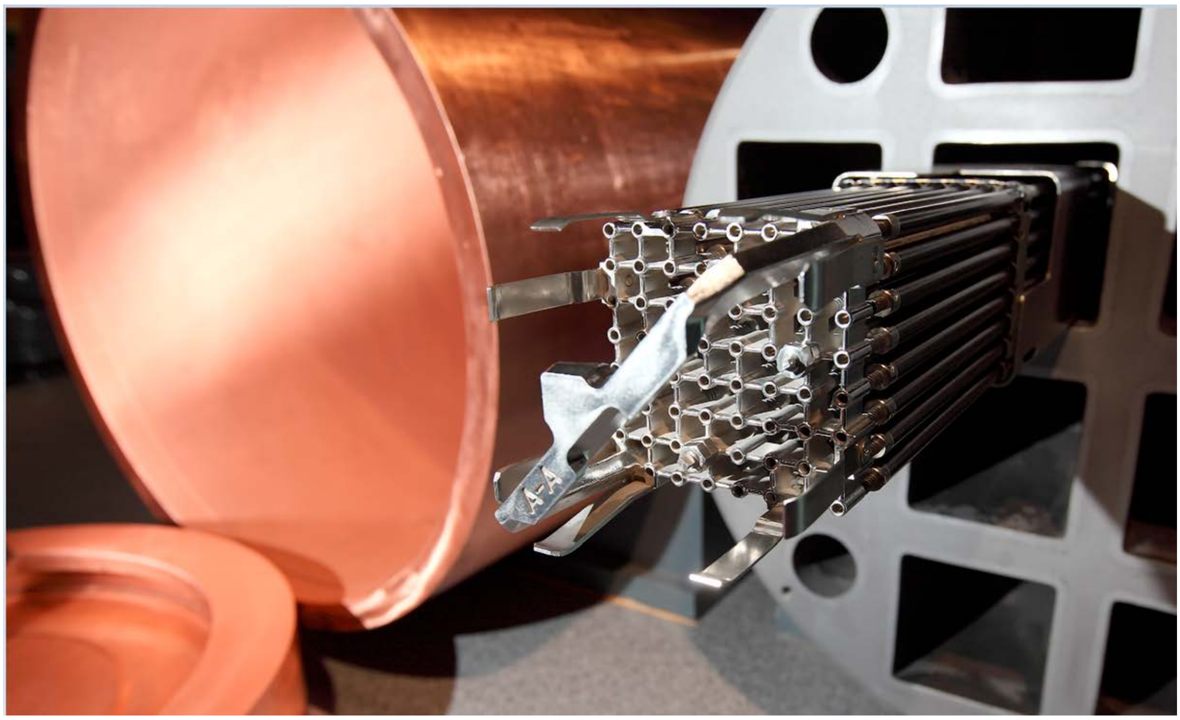


Figure 2. In final disposal, the most important systems are the spent nuclear fuel, the final disposal canister insert and copper canister. Other systems that, among other things, ensure long-term safety, maintaining fuel integrity, preventing the spread of radiation and radiation measurements, are included in the most important systems.

transport container transfer corridor, canister transfer corridor, fuel assembly handling cell, facilities necessary for canister sealing and inspections, and the interim storage for canisters waiting for placement in final disposal.

The underground disposal facility is divided into the disposal repository, where canisters containing spent nuclear fuel are placed, and other underground facilities, which include, among others, the central tunnels that connect deposition tunnels, vertical shafts and technical rooms, such as the rooms for temporary storage of sealed canisters that contain spent nuclear fuel.

Posiva's disposal facility complex does not have systems, structures or components whose safety significance would require classifying them into the highest Safety Class SC1. The spent nuclear fuel, final disposal canister and drying station fuel rack are classified into Safety Class SC2.

Systems, structures and components that are significant in terms of nuclear safety and, thereby, are in the Safety Class SC3, include the following, for example:

- transport container and transfer cask for the transport of spent nuclear fuel and the related handling systems
- fuel handling cell
- spent fuel handling equipment
- spent fuel element drying system
- sealed canister handling equipment
- radiation controlled area ventilation and filtration equipment
- radiation measurement equipment
- equipment necessary for release monitoring.

The long-term safety of final disposal is based on separating radioactive substances from the environment by means of engineered release barriers, which are designed to function for as long as the radionuclides contained inside the spent fuel could pose a significant harm to the environment. Based on long-term safety, the following are classified in Safety Class SC3::

- deposition holes, deposition tunnels and their backfill
- central tunnels and tunnel backfill.

Most of the systems, structures and components of the encapsulation plant and disposal facility are in the safety class EYT/STUK or EYT.

THE LONG SERVICE LIFE OF THE NUCLEAR WASTE FACILITIES IS ENSURED THROUGH AGEING MANAGEMENT

The primary aim of Posiva's ageing management is ensuring nuclear safety at all the stages of final disposal activities and the management of the related facility complex throughout the service life. The level of nuclear safety will be kept high by implementing ageing management measures to the extent required by the safety significance of the different plant components. In addition to safety, high-quality implementation of ageing management contributes to the appropriateness of maintenance activities, among other things.

Ageing management helps ensure that the different plant components meet their functional requirements specified at the design stage throughout the service life with a sufficient safety margin. Should ageing management measures detect that a plant component is ageing prematurely before the end of its planned service life, the effects from ageing can be managed safely without compromising the safety of the system, component, structure or the overall activities. On the other hand, successful ageing management allows for using plant components longer than their original design life. Ageing management is carried out systematically also through the facilities' consistent development, maintenance, modernisations, equipment modifications and equipment replacements in order to promote safety and production reliability based on operating experience.

Ageing management covers the facility complex related to Posiva's final disposal activities, comprising the encapsulation plant and disposal facility, and it primarily examines the plant components significant to nuclear safety based on the safety classification of the systems, structures and components.

For the systems, structures and components important in terms of nuclear safety that have been included in the scope of ageing management, more detailed ageing monitoring and related reporting procedures are applied. In addition to the aforementioned, the condition monitoring and maintenance actions are used for managing the ageing of all the other plant locations.

In practice, system and equipment owners acting as experts in their area of responsibility have a significant role in the implementation of the ageing management measures. The persons responsible monitor and report matters concerning the maintenance of the plant component in question and, if necessary, initiate actions in order to manage the effects of ageing proactively and safely. The sufficient competence level of the personnel is ensured through regular assessments, and their expertise is developed with training, among other things. Where necessary, external expertise is available, for instance via Posiva's owner companies: Teollisuuden Voima and Fortum Power and Heat.

In terms of ageing management, special characteristics of the final disposal of spent nuclear fuel include the following:

- long time span of the operations,
- low number of processes that involve a medium,
- significant role of rock engineering,
- underground environmental conditions,
- significantly high local radiation levels (dry processing of fuel), and
- the various temporal stages of final disposal activities.

The designed service life of the encapsulation plant and disposal facility is approximately 100 years and, therefore, technological ageing management has a special role.

The durations of the different stages of operations have been considered in the design requirements, for instance when determining the design service life, which is, primarily, 30 years for technical equipment and 100–120 years for rock structures. The encapsulation plant and the ventilation and lifting equipment buildings have a design service life of 100 years.

OPERATIONAL SAFETY TAKES INTO ACCOUNT THE POSSIBILITY AND PREVENTION OF HUMAN ERRORS

The actions for ensuring safety involve the management of human errors. The principles for human error management can be roughly divided in two:

Figure 3. Posiva's overground facility area. At the front is a visualisation of the encapsulation plant

- Organisational methods
- Technical procedures

Organisational methods are administrative procedures for identifying and avoiding human errors. They include processes for preparing, inspecting and approving documents in order to ensure that the solutions have received the processing appropriate for their safety significance in the organisation and between organisations, and that the solutions are in line with the management expectations. In order for such a process to work, the organisation and the management system must be established such that the practices are clear and they support the performance according to the responsibilities and obligations.

The technical procedures for compliance with the safety requirements and avoiding human errors are based on the specification of technical requirements and their development into safe and functional design solutions and, further, into structural plans for implementation. Human–system interaction in the operation of the nuclear facility's systems is also a potential source of human errors. Human–machine interaction is managed with Human Factor Engineering (HFE).

Perhaps the most significant principle concerning the management of human factors at the nuclear facility is tolerating a single failure without significant consequences. The principle is applied both technically and administratively. Single-failure tolerance means a technical solution or operating model in which an error in an individual factor or equipment failure cannot cause a function unfavourable for safety.

Human error prevention uses methods that verify safety, including peer checking, independent verification, pre- and post-job briefings and verified communication. These verifying methods ensure that no one performs actions that are significant for safety alone without verification or based on incomplete situational awareness. These tools are used in technical as well as administrative solutions throughout the nuclear facility's service life in the design, construction, operation and decommissioning.

IN NUCLEAR WASTE FACILITY DESIGN, THE STARTING POINT COMPRISES SAFE OPERATION AND ENSURING LONG-TERM SAFETY

Posiva has made the following decisions and choices of reference solutions that have been taken into account in the final disposal of spent nuclear fuel as well as the structures and technology of the encapsulation plant and disposal facility.

- The final disposal solution is a vertical deposition solution (KBS-3V), in which the canisters are placed in vertical holes drilled into the deposition tunnel floor.
- The encapsulation plant is located above the disposal facility, and it connects to the underground facilities of the disposal facility via a canister shaft.
- The reference method for the canister copper lid welding is friction stir welding, FSW.
- The reference methods for inspecting the canister weld are visual, ultrasonic and eddy current inspection.
- The canisters are transported from the encapsulation plant to the disposal facility by means of a canister lift.
- The spent fuel from Loviisa is transported by road in a vehicle to Olkiluoto as a dry transport.

The spent fuel from Olkiluoto is transferred to the encapsulation plant as an internal transfer within the nuclear power plant area as a wet transport.

- The disposal repository is located on one level underground at an elevation of 400...-450 m.
- The deposition tunnels are backfilled with a granular material made of bentonite.

Other basic principles in the design:

- The plans take into account the fuel quantities and fuel properties of the Olkiluoto 1, 2 and 3 (OL1, OL2, OL3) and Loviisa 1 and 2 (LO1 and LO2) plant units.
- The existing infrastructure in Olkiluoto will be utilised as much a possible.
- The plant designs will include preparations for the retrieval of final disposal canisters.
- The requirements of nuclear safeguards will be taken into account.
- The combination of the underground research facility (ONKALO) and the disposal facility will be taken into account.
- The encapsulation plant and disposal facility have long service lives of approx. 100 years.
- The plan-in-principle concerning the expansion of the disposal repository has taken into account the favourable decisions-in-principle for the final disposal of the plant units' fuel, amounting to a total quantity of 6,500 tU of fuel and approximately 3,300 final disposal canisters at the disposal facility.

The average encapsulation efficiency of the encapsulation plant is approximately 40–50 canisters annually. The maximum encapsulation efficiency is 100 canisters annually. All work steps at the encapsulation plant are designed so that they can be carried out safely and without significant releases or radiation doses to personnel. Even in case of an operational occurrence, the encapsulation process will remain in a controlled state.

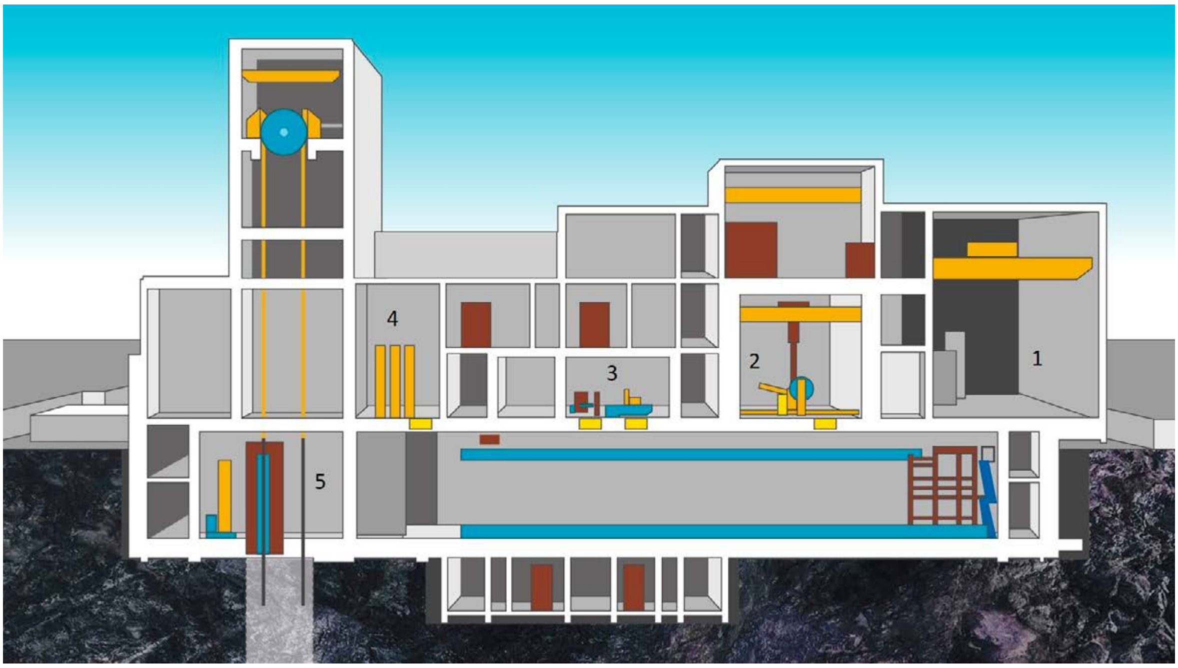
The disposal repository will be located at an elevation of -400...-450 metres, mainly at a depth of approximately 430 metres. The disposal repository is dimensioned for 6,500 tU of fuel. The extent of the disposal repository is designed for a 5% higher number of canisters than required for the disposal of the planned fuel quantities. The applied margin is based on the Rock Suitability Classification (RSC) assessment of the Olkiluoto bedrock degree of availability. The final dimensioning of the disposal repository will be updated as more specific information on the bedrock becomes available. Furthermore, if the final waste quantity changes, it will affect the dimensioning of the repository. Therefore, dimensioning will only be completed at the end of the disposal repository's operating phase when the last deposition hole has been drilled and approved for use in final disposal.

The facilities have been designed and implemented with methods according to a configuration management plan and a design process in which the planning is based on technical requirements specified in advance. The fulfilment of the specified requirements has been verified at the different phases of implementation such that it has been possible to confirm compliance. The specified requirements are also important for future plant modifications, at which point these existing requirement specifications can be used as design basis for the modifications.

THE NUCLEAR WASTE FACILITIES ARE LOCATED IN THE OLKILUOTO POWER PLANT AREA

Posiva's spent nuclear fuel encapsulation plant and disposal facility will be built on the island of Olkiluoto in southwestern Finland. The island of Olkiluoto is located in the municipality of Eurajoki, approximately 13 kilometres north of Rauma and approximately 34 kilometres southwest of Pori. Olkiluoto is a large island (approximately 12 km2), separated from the mainland by a small strait. The encapsulation plant will be located in the central part of the island in the Posiva nuclear facility area. The spent fuel disposal facility will be located at a depth of approximately 430 m in the central parts of the island. According to a decision-in-principle made by the Finnish Government in 2000, the location of the spent nuclear fuel encapsulation plant and disposal facility is Olkiluoto Island in Eurajoki.

The location of the encapsulation plant and disposal facility of Posiva meets the requirements for land use set out in legislation and in the guidelines for nuclear power plants (YVL Guides) issued by the Radiation and Nuclear Safety Authority. Land use in the Olkiluoto power plant



■ **Figure** 4. Longitudinal cross-section of the encapsulation plant. On the right, there is the reception and storage room for transport containers and transfer casks (1). To the left, there are the fuel handling cell (2), copper lid welding machine and the machining and inspection station (3), reception and storage facility for empty canisters (4) and the canister lift (5).

area is presently controlled by the provincial plan, the partial master plan for Olkiluoto and local detailed plans that have been validated in 2014. The location of Posiva's nuclear facilities in the Olkiluoto power plant area allows for the implementation of safety and emergency preparedness arrangements. The location of Teollisuuden Voima Oyj's (TVO) nuclear facilities in the same power plant area also minimises the harm and threats to the environment from operation and contributes to operational safety. Appendix 3 to the operating licence application describes the location more extensively.

RADIATION SAFETY TO THE PERSONNEL AND THE ENVIRONMENT IS ENSURED IN THE OPERATION OF THE NUCLEAR WASTE FACILITIES

The radiation doses caused by the possible releases from the encapsulation plant and disposal facility as a result of normal operation, operational occurrences and accidents have been analysed extensively. The reported radiation doses are calculated for a representative person representing a small population of a sufficiently consistent age and lifestyle that receives the highest exposure. In the sparsely populated surrounding environment of the encapsulation plant, an adult is a natural and justified choice as the age group of a representative person. Another factor in favour of choosing adults as the age group is that radioactive iodine I-131, which is significant for radiation doses incurred by children, has already decayed practically completely, as the spent fuel has cooled for a long time, and there are no dairy farms in the immediate vicinity of the encapsulation plant. The radiation doses incurred by a representative person are reported conservatively at the highest dose calculation point. Typically, the highest dose is incurred near the encapsulation plant where there is no permanent residence.

Based on the analysis results, it can be stated that the radiation doses do not exceed the specified radiation dose limits in any discussed scenario. In normal operation, the annual radiation doses incurred by the surrounding population remain negligibly low; the radiation dose incurred by a representative person comprises approximately 0.001% of the annual dose limit for normal operations (0.01 mSv). In operational occurrences, the doses are, similarly, negligible; the radiation dose incurred by a representative person comprises approximately 0.002% of the annual dose limit (0.1 mSv). Even in accident scenarios, the doses to the representative person will remain clearly below the annual dose limits. A situation relatively closest to the annual dose limit would be reached in a very rare scenario in which a fuel transport container falls the highest possible distance at the encapsulation plant and the fuel inside the container becomes damaged. With a conservative assumption that, concurrently, the plant loses its power and a release into the outside air takes place through the unsealed openings in the building, a representative person would incur a dose of 2.30 mSv, which amounts to approximately half of the annual dose limit of 5 mSv.

The collective radiation dose of the personnel at the encapsulation plant and disposal facility is kept as low as reasonably achievable (ALARA). The activities are designed such that the effective radiation dose incurred by an employee remains clearly below individuals' dose limits. According to the dose limits, an employee's dose may not exceed 20 mSv in one year. Furthermore, the plant and facility have set a target for individual persons to not receive an external radiation dose of more than 5 mSv annually.

Most of the radiation exposure by personnel at the encapsulation plant occurs due to the work stages concerning the reception of a transport container, which requires working near the container. The transport container used for dimensioning for radiation levels is a gas-filled transport container from Loviisa, which may include up to 84 fuel assemblies at a time. The allowed maximum dose rates are 2 mSv/h at the transport container's surface and 0.1 mSv/h at a distance of one metre.

In most of the other work stages, the work is carried out remotely from a control room, and the facilities use structural radiation shielding that attenuates background radiation to a very low level. Structural radiation shielding is based on fixed solutions, such as radiation shield walls made of reinforced concrete and labyrinth structures.

SAFETY PRINCIPLES OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

THE SAFETY OF THE NUCLEAR WASTE FACILITIES IS ENSURED BY FOLLOWING A STRUCTURAL DEFENCE-IN-DEPTH PRINCIPLE

The encapsulation plant and disposal facility follow a structural defense-in-depth principle in order to prevent radioactive substances from spreading into the environment. At the encapsulation plant, the release barriers preventing the spreading of radioactive substances contained in spent nuclear fuel include the transport container or transfer cask, handling cell and the other structures of the radiation controlled area, and the final disposal canister. Moreover, at the disposal facility, the release barriers for radioactive substances include the release barriers installed around the final disposal canister for long-term safety as well as the bedrock.

At the encapsulation plant, four levels of functional defence-in-depth are applied. The design takes into account defence levels that are as independent as possible: prevention, management of operational occurrences, management of accidents and mitigation of consequences. In order to apply the defence-in-depth principle at the disposal facility, any functions whose failure could cause an accident leading to a significant release of radioactive substances or the radiation exposure of the facility personnel are backed up.

At the encapsulation plant and disposal facility, the functional defence-in-depth principle is primarily applied through the prevention of operational occurrences and accidents, i.e. ensuring that the operation of the facility is reliable and deviations from normal operating conditions are rare. This means that the facilities are operated according to approved operating procedures; the facilities' environmental conditions remain as planned both in terms of the facilities' systems and the operating personnel; systems implementing a safety function work as expected; and the operational systems related to fuel transfers, lifting and handling function in a way that maintains the fuel elements' integrity and tightness. Furthermore, applicable practices will be planned for the handling of damaged fuel elements. Control I&C performs the facility's adjustment and control functions and acts as the operator's monitoring system and the transmitter

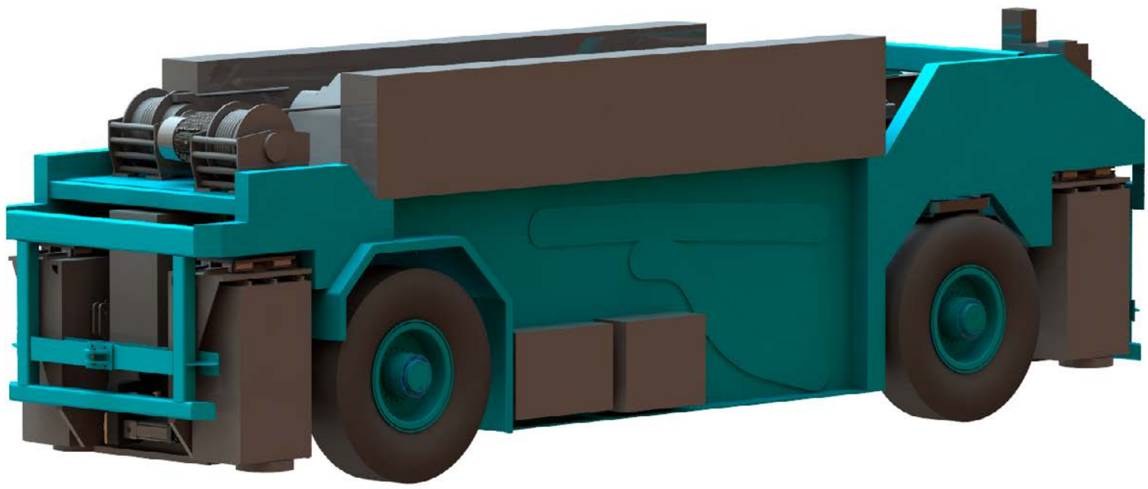


Figure 5. A final disposal canister that contains spent nuclear fuel is always handled in a radiation safe manner. The figure presents a visualisation of the canister transfer and installation vehicle, which is used for transferring canisters shielded inside a radiation protection tube.

of manual control actions. The adjustment and control functions of control I&C monitor the safe limits set for activities.

At the encapsulation plant and disposal facility, the management of operational occurrences means ensuring the nuclear fuel's reactivity management and decay heat removal. The encapsulation plant must also ensure the integrity of fuel cladding during the handling of fuel. Decay heat removal is managed by ensuring that the handling systems for fuel or final disposal canisters do not unnecessarily prevent the release of decay heat. The encapsulation plant has no separate systems designed for reactivity management. Rather, reactivity is managed through the structural properties of systems used for the short- or long-term containment of nuclear fuel. Protection I&C monitors that the process is kept in a controlled state. If protective limits are exceeded in the process, protection I&C implements protection measures and takes the process into a controlled state.

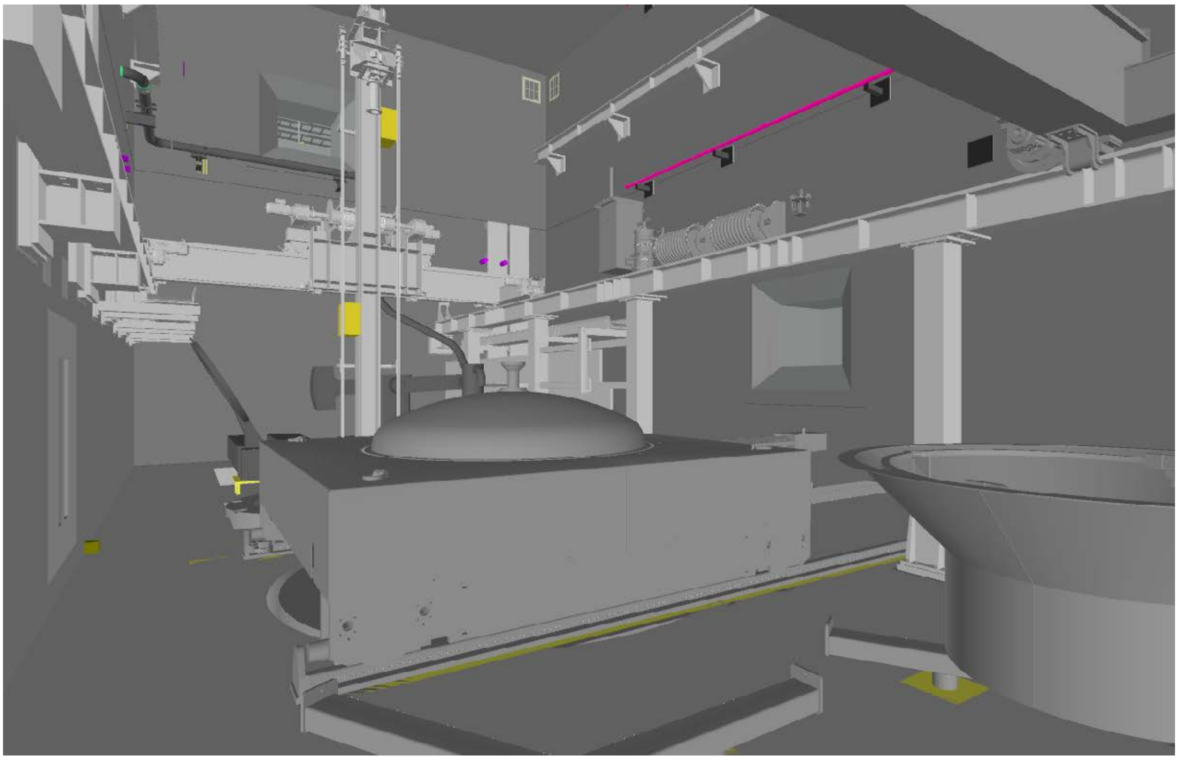
At the encapsulation plant and disposal facility, the management of accidents means ensuring that the ventilation filtration of the encapsulation plant and disposal facility is functional in scenarios where the integrity or tightness of the fuel cladding and, in the case of the disposal facility, also the tightness of the final disposal canister, is lost. If necessary, it is also possible to close release routes by closing ventilation dampers, as decay heat removal does not require active ventilation. Temperature and radiation measurements are used for ensuring that the situation is under control. If the containment of radioactive substances fails and radioactivity is released from the encapsulation plant or disposal facility, the radiation effects on the personnel and population are limited by means of emergency preparedness arrangements.

NUCLEAR WASTE FACILITIES' SAFETY FUNCTIONS INCLUDE THE MANAGEMENT OF NUCLEAR FUEL AT ALL THE PROCESSING STAGES

In the processing and storage of spent nuclear fuel, sufficient cooling of the fuel shall be ensured and any damage to the fuel and the occurrence of a self-sustaining chain reaction of fissions shall be prevented. Based on this, the safety functions of the encapsulation plant and disposal facility have been defined as decay heat removal, management of radioactive substances and reactivity management.

When spent nuclear fuel is brought to the encapsulation plant, it has cooled for at least 20 years, but more likely 30–50 years after it has been removed from the reactor.

By this time, the fuel elements' heat generation has reduced to approximately one thousandth. The decay heat generated in the fuel is transferred from the spent nuclear fuel to the surrounding processing facilities, from where the



■ **Figure** 6. View from inside the fuel handling cell. Image from the facility model.

heat is removed through passive conduction and active extraction with the ventilation systems. From a canister placed in final disposal, decay heat is transferred into the bedrock. In terms of decay heat removal, it is essential to ensure that the structures of systems that contain or handle fuel do not unnecessarily prevent the removal of decay heat from the spent nuclear fuel.

Control of radioactive substances at the encapsulation plant and disposal facility includes ensuring the integrity of fuel cladding, preventing and limiting the spread of radioactive releases and limiting the radiation exposure of the population and personnel. Furthermore, radioactivity and dose rate measurements are used for monitoring the facility's premises and possible releases into the environment. Control of radioactive substances also involves the careful processing of radioactive substances accumulated from decontamination, radioactive wastewater and solid low and intermediate-level waste. The essential radioactive substance management tasks that focus on the facilities' systems are related to ensuring the integrity and tightness of the systems and structures that contain radioactivity. This is carried out by preventing collisions and drops of heavy loads and ensuring the negative pressure levels, filtration and, where necessary, isolation.

Reactivity management at the encapsulation plant and disposal facility has been addressed in the design of systems containing nuclear fuel and systems used for processing and transfers primarily through structural solutions. The materials and geometry of fuel racks have been selected such that a critical configuration cannot be created. Furthermore, the encapsulation plant prevents water from entering the space between fuel elements by structural means and by limiting the amount of flooding water that can enter the handling cell to a very small amount.

THE NUCLEAR WASTE FACILITIES PREVENT THE SPREAD OF RADIOACTIVE SUBSTANCES

The encapsulation plant primarily handles intact fuel, in which case the fuel cladding is the first release barrier. However, the encapsulation plant also allows for encapsulating fuel that has lost its tightness, in which case the other engineered release barriers ensure the management of radioactive substances.

The fuel handling rooms and systems are designed such that the integrity of the fuel rod cladding is maintained with a high degree of certainty. Maintaining the integrity of the cladding is particularly important in the handling cell of the encapsulation plant, which is the only place at the encapsulation plant and disposal facility where nuclear fuel is handled without shielding. Elsewhere at the encapsulation plant and disposal facility, spent nuclear fuel is handled in a transport container or canister, which provide radiation shielding and prevent radioactive substances from spreading in case of fuel rod failures.

The structures of the handling cell limit the release of radioactive substances in case of events inside the handling cell that lead to fuel failures or when handling leaking fuel. The tightness of the handling cell is ensured by maintaining the tightness of the handling cell's openings and penetrations. The spread of radioactive substances is also limited by active systems that are related to the tightness of the handling cell, maintaining a negative pressure in the handling cell and the radiation controlled area, and the filtration of the handling cell air.

The handling cell is surrounded by the other structures of the encapsulation plant that provide protection against internal and external threats. All systems that can potentially contain radioactivity are located within the radiation controlled area in rooms whose drains and ventilation are separated from those of the other parts of the building. In case of radioactivity being released, the water can be collected into the radiation controlled area's drain collection tanks and the radioactivity released into the air can be filtered out by the radiation controlled area's exhaust ventilation system.

The disposal facility only processes canisters that have been found to be free of contamination. Therefore, at the disposal facility premises, it is essential to protect the personnel against direct radiation from the final disposal canisters by means of distances and radiation shields. At the same time, the radiation shield structures protect the canisters against falling boulders, for example. When a canister is being transferred to a deposition hole, the radiation shield of the canister transfer and installation vehicle protects the canister. Immediately after installation into a deposition hole, a bentonite buffer is installed on top of the canister. The buffer reduces the radiation dose rate to the level equivalent to background radiation and protects the canister against falling loads.

THE PROCESSING AND STORAGE OF OPERATING WASTE GENERATED AT THE NUCLEAR WASTE FACILITIES IS HANDLED SAFELY AT THE OLKILUOTO NUCLEAR POWER PLANT

Small amounts of low and intermediate-level nuclear waste are generated at the encapsulation plant during operation, maintenance and plant modifications, for example, due to the radiation of the nuclear fuel being processed. Posiva transfers the waste management obligation for this waste to Teollisuuden Voima Oyj (TVO), whose three nuclear power plant units are located on the same Olkiluoto Island. This means that the solid or liquid radioactive waste generated at the encapsulation plant are taken to the Olkiluoto nuclear power plants for clearance from regulatory control or processing, storage and, later, final disposal in the Olkiluoto VLJ cave or near-surface final disposal. TVO has more than 40 years' experience of nuclear waste.

However, Posiva is preparing for its own waste management by including space reservations for waste management systems at the encapsulation plant. Furthermore, Posiva has the space reservations for its own disposal repository for operating and decommissioning waste. According to tentative plans, this repository will be located at a depth of approximately 180 metres along the ONKALO driving route. This repository will likely be needed only after the operation of the Olkiluoto VLJ cave has ended, so it will not yet be constructed at this time.

Posiva ensures the safe processing and storage of spent nuclear fuel considered to be nuclear waste, and the final disposal process for the fuel, including its interim storage phases, has been planned to take into account sufficient fuel cooling, radiation protection and criticality safety. Fuel integrity is an essential element of final disposal activities. The tightness and mechanical durability of the fuel assemblies is confirmed, and the processing equipment are implemented such that fuel integrity can be verified

NUCLEAR WASTE FACILITIES HAVE PREPARED FOR EXTERNAL AND INTERNAL EVENTS THAT IMPACT SAFETY

The impacts of various internal and external threats on the safety of the encapsulation plant and disposal facility have been evaluated systematically. Threats that could compromise the facilities' safety have been identified and appropriate emergency preparedness plans and design bases have been presented for them in order to ensure that the threats will not pose an unreasonable risk to the facilities' safety and that the set safety targets can be achieved.

Due to the functions of the encapsulation plant, the most relevant internal risks could be fires as well as load drops or collisions. The safety significance of fires can be kept low through facility design and operating activities in line with the fire protection defence-in-depth principle. The parts and components important in terms of lifting are designed to be single-failure tolerant or, if this is not feasible, the safety of lifting operations shall be ensured by other means. For most of the encapsulation process, the nuclear fuel is either inside the fuel transport container or a final disposal canister. This provides the fuel elements with good protection against various threats. In terms of internal threats, it is essential to ensure that no potential threat can simultaneously lead to a release of radioactivity and unsuccessful prevention of its spreading. The typical response includes stopping the encapsulation process and ensuring the safety of the situation.

Sudden external phenomena are considered conservatively in the design of structures, systems and components important for safety, because separate special measures for preparedness or ensuring the safety of the facility may not necessarily be even possible. Such threats include earthquakes, storm winds, heavy rains and thunder. Possible separate preparedness measures can be considered for foreseeable threats that develop slowly. An ongoing encapsulation process can be stopped, the plant can be operated into a safe state, the cleanliness of the radiation controlled area can be ensured, and special practices and equipment designed for such scenarios can be introduced. Such foreseeable phenomena include very high or very low air temperature as well as special work involving an elevated risk of accidents being carried out in or near the plant area.

One inherent characteristic of external threats is that several threats can be interconnected and have a concurrent impact on the facility. Typical threats that have a higher risk of concurrence compared to independent events include storm winds and lightning strikes, storm winds and heavy rains, high air temperature and forest fires, and high air temperature and high seawater temperature. Regarding the encapsulation plant, it is noteworthy that the plant is not dependent on seawater-based systems and that it is located approx. 10 m above sea level. Therefore, threats relating to seawater phenomena are not relevant for the plant.

When preparing for external threats, it is essential to ensure that no sudden imaginable phenomenon can lead to the impairment of strength of structures important for the safety of the encapsulation plant. Even if most or all of the nuclear fuel located at the plant were protected by a transport container or a final disposal canister at the time of the event, a possible full or even partial collapse of wall or roof structures would, in any event, jeopardise the integrity of the radiation controlled area and could lead to leaks of radioactive waste systems, at a minimum. Preparing for this allows for assuming, in principle, that various external threats will not result in a significant threat to nuclear safety or the containment of radioactivity and, instead, the possible effects will affect the availability of the facility, at most.

The disposal facility has good structural and passive nuclear safety properties. The nuclear fuel is located inside a tight final disposal canister throughout the final disposal process. The canister protects the fuel against drops, fires, explosions and collapses. At the same time, it prevents the spread of possible radioactivity. Furthermore, during the transfer process the radiation shield of the canister transfer and installation vehicle protects the final disposal canister. The bedrock surrounding the underground premises of the disposal facility provides a stable environment.

Fires, structural collapses, explosion accidents and floods caused by groundwater leaking from the bedrock can be, justifiably, considered to be the most essential risk factors at the disposal facility. Operating deep underground poses a particular challenge, as it limits the opportunities for rescue operations and operational firefighting. Many internal threats involve a risk to personal safety. The expansion of the disposal repository during the final disposal operations requires careful administrative procedures and a clear separation of the premises being used and those under construction. This allows for ensuring that the construction work and the related blasting do not compromise the storage of final disposal canisters or their transfer operations.

Regarding the disposal facility's systems and support functions, it should be noted that part of the equipment and equipment rooms are located in overground buildings (lifting equipment building, ventilation building, tunnel engineering building, encapsulation plant). Therefore, any accidents taking place in these buildings, such as fires or explosions, can affect the functionality of the underground disposal facility's systems. However, possible accidents will not have a considerable nuclear safety significance, as even if they resulted in an interruption of electrical distribution, ventilation, cooling, heating, extraction pumping of leakage water, or access by personnel, fuel integrity can still be secured.

The disposal facility located deep underground is better protected against various external threats compared to the encapsulation plant. It can therefore be stated that it is highly unlikely that any external threat could directly impact the nuclear safety of the disposal facility. The loss of the support functions could compromise the facility's normal operation and, in a worst case scenario, lead to the disposal facility becoming flooded to some extent as a result of the leakage water extraction pumping stopping. Sufficient protection of the overground facilities is important for personnel safety, the facility's availability and prevention of significant financial damage. However, in terms of nuclear safety, the imaginable internal or external threats do not pose a significant risk to the disposal facility.

THE MONITORING AND CONTROL OF NUCLEAR WASTE FACILITIES IS DESIGNED TO BE SAFE

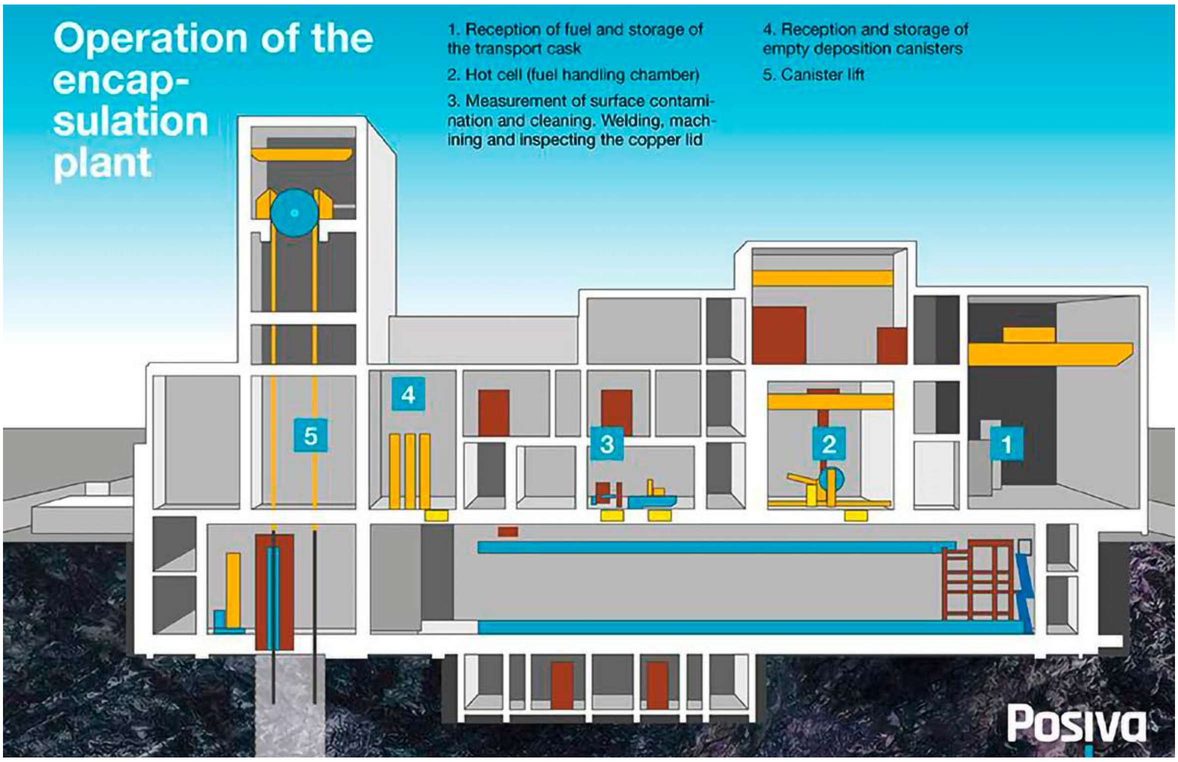
The main principle of controlling the encapsulation plant and disposal facility is that the fire protection, radiation protection and encapsulation process protection functions are mainly automated. Most of the operating functions are controlled by semi-automatic sequential controls, i.e. the operator indicates when the control system can proceed with the next process stage.

The encapsulation process is controlled and monitored from the encapsulation plant control room. The control room is located in the immediate vicinity of the handling cell, and it has visual contact with the handling cell via a lead-glass window. Most of the functions in the production state are controlled from the control room, excluding the functions with only local control, such as the plant's overhead crane controls. In the plant's production state, the protection and safety functions are also monitored from the control room.

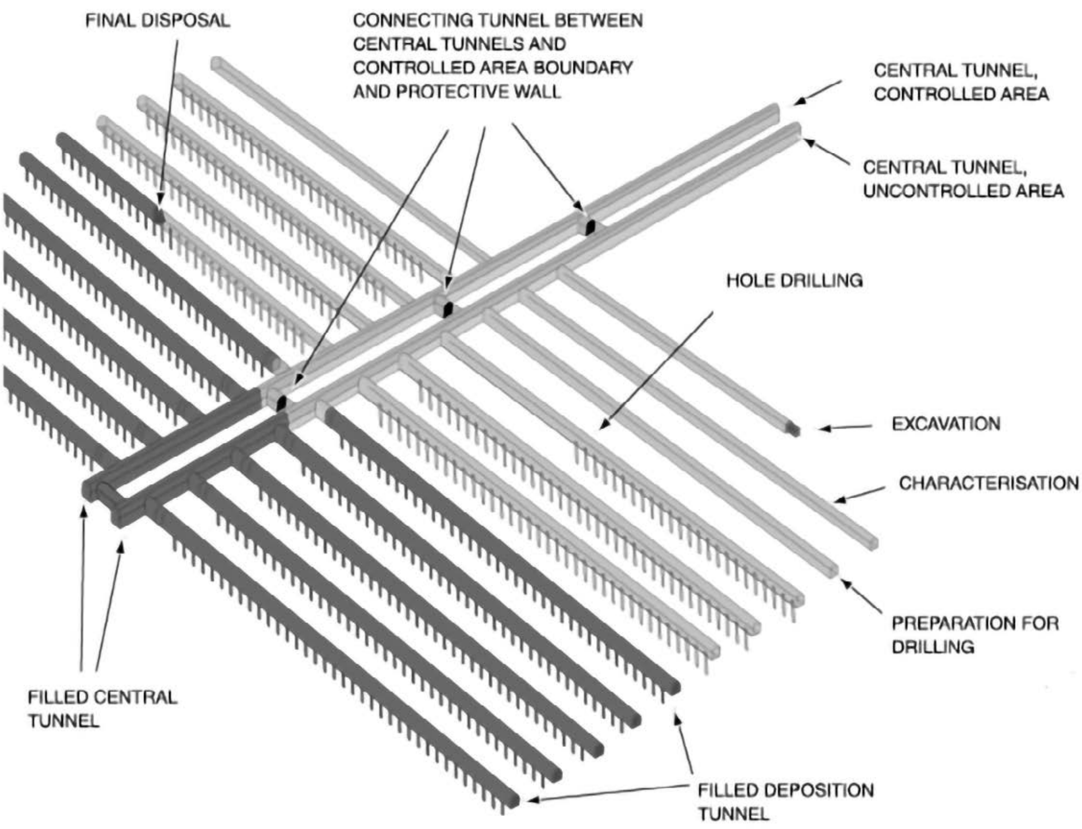
The monitoring room for the disposal facility is the operating centre of the lifting equipment building. Furthermore, the disposal facility has local control stations for rock engineering and final disposal process control. The back-up control station of the disposal facility is located in the tunnel engineering building. For emergency preparedness scenarios, the disposal facility's alarm and room information is also available in Posiva's support group premises at the lifting equipment building. The lifting equipment building operating centre is also used for monitoring the encapsulation plant's premises, and it is manned even when there are no active operations taking place at the encapsulation plant.

Monitoring of ventilation systems

Ventilation systems are used for monitoring items such as negative pressure in rooms and flow directions in order to prevent the spreading of possible radioactivity. If necessary, exhaust air is passed through filters and ventilation lines are closed. Functions significant for safety are mainly implemented automatically, controlled by the control I&C system, protection I&C system and radiation measurement systems. Ventilation system monitoring is primarily based on tracking alarms and responding to them, as necessary.



■ **Figure** 7. Cross-section of the encapsulation plant and the different functions.



■ **Figure** 8. Parallel tunnel principle allows for better availability and fire compartmentation, among other things.

The monitoring takes place in the production state at the encapsulation plant control room and in the maintenance state at the lifting equipment building operating centre.

Temperature monitoring

The temperature of premises containing fuel is monitored in the production state at the encapsulation plant control room. The temperature measurements of these premises are supplied by the back-up power system in case external power supply is lost. If the loss of external power supply lasts for more than 3 hours, temperatures are checked manually according to the round lists. The temperature of premises containing fuel is also monitored with mechanical thermometers.

Radiation monitoring

Radiation monitoring means tracking radioactivity in rooms, ventilation ducts and process systems that contain radioactive substances (such as wastewater and solid process waste). The radiation measurement systems trigger alarms due to excessively high radioactivity or dose rate levels, and the monitoring is mainly based on tracking these alarms. The monitoring takes place in the production state at the encapsulation plant control room and in the maintenance state at the lifting equipment building operating centre.

Fire monitoring

Fire monitoring is primarily based on tracking fire alarms. Alarms from the encapsulation plant's fire alarm system are communicated to the encapsulation plant control room, lifting equipment building operating centre, Olkiluoto alarm centre and the plant fire brigade (protection centre). The main operating equipment and separate graphical terminals for the fire alarm system are located in the encapsulation plant control room and in the lifting equipment building operating centre. Furthermore, parallel main operating equipment and graphical terminals are located in the Olkiluoto alarm centre and plant fire brigade (protection centre). The primary responsibility for fire monitoring lies with the encapsulation plant control room in the production state and with the lifting equipment building operating centre in the operational readiness and stop states.

Access control

Access control data and cameras are used in order to ensure that personnel cannot access the machine or radiation danger areas. Some of the facilities are also protected by means of automatic locking functions: for example, it is not possible to access the handling cell, drying station or the canister transfer corridor if the dose rate in these areas is too high or the process is in operation. Access control data relating to machine and radiation safety can be tracked at the encapsulation plant control room and the lifting equipment building operating centre. Responsibility for the monitoring lies with the encapsulation plant control room in the production state and with the lifting equipment building operating centre in the maintenance state.

Actions in case of operational occurrences

In an operational occurrence, the operators at the encapsulation plant control room and local control stations will stop the activities. If possible, the ongoing lifting operations are completed. The encapsulation process can be stopped at any time, bringing the plant into a controlled state. If an operational occurrence starts while the encapsulation process is not underway, the encapsulation plant control room will primarily not be manned. In this case, after receiving an alarm from the system, the primary task of the operator from the lifting equipment building operating centre, who is monitoring the encapsulation plant, is to call other personnel to assist with the situation.

In case of operational occurrences in the final disposal process, the operating shift members at the lifting equipment building's operating centre and local control stations as well as the other workers in the final disposal process shall interrupt the other operations; however, ongoing lifting operations shall be completed and radiation safety must not be compromised. Possible concurrent ongoing deposition tunnel rock engineering work may be continued, provided that the operational occurrence has no effect on the facility's nuclear and radiation safety or systems important for operational safety, such as ventilation, power supply or fire safety. In case of operational occurrences in the rock engineering process, the first priority is to ensure that systems important for operational safety, such as ventilation, power supply and fire safety, are functional.

DECOMMISSIONING SAFETY HAS BEEN CONSIDERED ALREADY IN THE DESIGN OF THE NUCLEAR WASTE FACILITIES

In connection with decommissioning, the encapsulation plant will be completely dismantled, and the equipment of the disposal facility is dismantled and all the open spaces are filled with compliant closure structures and materials. In connection with the decommissioning, the radioactive parts and systems of the encapsulation plant are dismantled and packed. The waste will be delivered to an operating and decommissioning waste facility, which would be tentatively located along the disposal facility driving tunnel at a level of approximately -180 m, or the Olkiluoto VLJ cave. The near-surface final disposal facility planned at Olkiluoto may also be relevant for part of the waste, depending on the type of the decommissioning waste.

The decommissioning of the facilities has been considered already during the facilities' implementation. The activation of the materials used in the facilities' implementation has been examined, and efforts to minimise the amount of activated material have been made already at the implementation phase. Furthermore, activation is tracked during the facilities' operation in order to minimise the radiation exposure of the personnel and limit the amount of generated radioactive waste at the facilities' decommissioning stage. A decommissioning plan is included in the documentation submitted to STUK and updated regularly during the facilities' operation.

SAFETY OF THE CONSTRUCTION AND COMMISSIONING OF THE NUCLEAR WASTE FACILITY

NUCLEAR WASTE FACILITIES ARE CONSTRUCTED IN A SAFE MANNER TO BE SAFE

The nuclear waste facilities – the encapsulation plant and disposal facility – have been constructed to be safe in accordance with the conditions presented in the construction licence issued by the Finnish Government and the construction permits issued by the municipality of Eurajoki. Posiva has established comprehensive procedures for construction and formed a competent and experienced organisation, which has supervised the implementation and its quality. As far as possible, reliable suppliers with experience in nuclear facilities have been selected for the construction work and they have also been required to have a competent and experienced organisation. The facilities' structures and systems have been classified according to their safety significance. In terms of safety classified structures, the design and implementation have been also supervised by the Radiation and Nuclear Safety Authority and independent inspection bodies that it has authorised.

The nuclear facilities have been constructed to be safe according to the requirements and approved plans. The end result has been verified with sufficient inspections and documented comprehensively.

THE NUCLEAR WASTE FACILITIES ARE COMMISSIONED SAFELY

The safety of the commissioning of a nuclear waste facility is managed by administrative commissioning guideline procedures and technical equipment-, system- and facility-level commissioning procedures, which are collected in the commissioning manual. The procedures present the approved methods and technical criteria for the performance and acceptance of each test. Furthermore, the operating procedures prepared for the operating phase will be validated during the tests. The validation ensures that the procedures are suitable for the safe operation of the facility.

Commissioning tests that are carried out before an operating licence is issued do not involve a risk of compromising nuclear safety, as no nuclear fuel is yet processed at the facility. In particular, the commissioning procedures ensure the

Figure 9. The final disposal functions of the encapsulation plant (visualised in the figure) and the disposal facility are designed to be radiation safe.

industrial safety of the commissioning personnel as well as compliance with the requirements set for the safety and functionality of the facility to be commissioned.

SAFETY OF THE OPERATION OF THE NUCLEAR WASTE FACILITY

THE OPERATION OF THE NUCLEAR WASTE FACILITIES IS SAFE

Posiva's operational activities include producing final disposal canisters at the encapsulation plant and installing final disposal canisters, bentonite buffers and tunnel bentonite backfill material at the disposal facility as well as related work, such as radiation protection, canister load planning, nuclear material accounting, operation planning and maintenance. The Production organisation, which is still being built along the construction and commissioning, is responsible for operational activities. The organisation is partly made up of in-house personnel, but areas involving group synergies, such as radiation protection and maintenance, also use TVO's resources. The Production Manager is the responsible manager for the operation of the nuclear waste facilities. The facilities being constructed and their future operation are new, so one-time establishment of the functional prerequisites for the line in production is carried out in projects. This will take place in the Preparation for Production (Tuotantoon valmistautuminen) programme and its sub-projects, which are part of the project phase.

The facilities' organisation, management relationships and decision-making bodies essential for operating activities are described in the administrative rules. More detailed tasks and responsibilities of the different organisations are described in field of engineering-specific manuals, such as the operations manual and radiation protection manual.

The operating activities will primarily take place during normal day hours, as the main process of the facilities' operation comprises mechanical transfer and assembly based on an input principle. The actual operation involves operators who perform remote control actions and a crane operator and operating personnel who perform field actions. In particular, the operators control systems that have a high level of radiation during the handling of fuel or a final disposal canister. Actions performed locally on the field include, among others, the assembly of canister components and lowering them on the production line, transfers, handling and preparation of the spent fuel transfer cask and, at the disposal facility, the traffic and reception relating to bentonite clay. These actions are supported by radiation protection which, on the one hand, ensures the safe performance of work and, on the other hand, in line with the zone approach, keeps the contamination near its place of origin without spreading it with persons or goods

The Operations Manager or their deputy acts as the supervisor of the operators and operating personnel. This person is responsible for ensuring that the facilities are operated according to the

Technical Specifications and that the work is carried out according to the work permit process. Production is based on the input principle, and production planning is carried out by the Operations Planning Engineer; this person works in close collaboration with the Fuel Engineer who makes the loading plans for the final disposal canister and transfer cask.

There are procedures for the facilities' normal operation, operational occurrences and accident scenarios as part of the operating manual. Normal operation procedures are used for performing operation actions according to production, which progresses based on the input principle, or for restoring systems to the initial state. Procedures for operational occurrences and accident scenarios are used for first identifying the deviating situation and then managing and controlling the situation according to the procedures. These procedures are based on the operational occurrences and accidents considered in the facility design.

Ensuring competence is a continuous activity at Posiva, and the personnel receive the training according to their duties' special requirements. Special requirements for competence come from the facilities' technology, uniqueness of the final disposal process and practices of the nuclear facilities. Transitioning from the facilities' construction and commissioning phases to the nuclear facility operating phase has been taken into account in the personnel training.

There is a separate management process for managing the implementation of plant modifications. First, the modification is planned and, depending on its safety significance, submitted to the Radiation and Nuclear Safety Authority for approval. The technical support organisation is responsible for planning, and the planning involves updating the essential design documentation according to the modification. At the modification implementation stage, the necessary dismantlement, installation and parameter changes are carried out at the facility and it is ensured that the documents necessary for operating and maintaining the facility are updated according to the modification.

Maintenance is an ongoing activity, part of which is completed during production and part during outages. The safe management of maintenance work and production is ensured with a work permit process, which guides the scope of the actions for implementing work tasks and the consecutive or parallel performance of the tasks. Within the scope of actions, additional sub-permits, such as a radiation work permit or a confined space permit, may be added to a work permit. When work tasks are performed consecutively, for example a maintenance work permit for a room with a high radiation level during production is released for implementation only after the processing of fuel or a final disposal canister, which generates radiation, has ended.

OPERATING EXPERIENCE AND SAFETY RESEARCH ARE UTILISED IN IMPROVING SAFETY

Posiva investigates the operational events significant for safety for the purpose of identifying the root causes as well as for defining and implementing the corrective and preventative measures.

At Olkiluoto, operating experience activity is a joint, group-level activity between TVO and Posiva. The Group's operating experience activity is managed by the Operating Experience group, which is tasked with the systematic tracking of operating experience reports comprising national and international operating experiences and observations for improving activities, delivering the reports for processing and following up on actions.

Posiva submits to the Operating Experience group for tracking and processing any significant operational events and observations for improving activities identified within Posiva's industry or operations (including events relating to rock engineering and long-term safety). Sources of operating experience at Posiva are the operating experience, deviations, safety observations, environmental damage, accidents and any other observations recorded in the deviation system as well as the performed trend analyses and summaries.

TECHNICAL SPECIFICATIONS HAVE BEEN CREATED FOR THE NUCLEAR WASTE FACILITIES

Technical Specifications (TechSpecs) concerning the encapsulation plant and disposal facility have been prepared and submitted to STUK for approval. TechSpecs describe the conditions, requirements and limitations for operating the encapsulation plant and disposal facility without compromising nuclear safety. TechSpecs include the technical and administrative requirements for ensuring the facility's operation in compliance with the design bases and safety analyses. The encapsulation plant and disposal facility will be operated subject to the requirements and limitations of the operating conditions in TechSpecs, compliance with them is supervised and any deviations from TechSpecs are reported. In addition to TechSpecs, procedures concerning the operation, operational occurrences and accidents will be prepared for the encapsulation plant and disposal facility.

THE CONDITION OF NUCLEAR WASTE FACILITIES IS MONITORED IN ORDER TO ENSURE SAFETY

Operability and the effects of the operating environment will be monitored by means of inspections, tests, measurements and analyses. Operability will be ensured proactively through regular servicing, and preparations for overhaul and repairs shall be made in order to prevent the degradation of operability. To enable this, maintenance is based on planned activities.

Maintenance planning

The purpose of maintenance is to contribute to the safe operation of the facility without disturbances and ensure reliable and competitive electricity production for the shareholders. In terms of maintenance planning, this means that:

- Maintenance shall be focused on equipment locations that are important for the facility's safety and availability and unnecessary actions are avoided.
- Sufficient readiness for defect repairs shall be ensured.
- The necessary maintenance resources shall be determined and secured.
- The necessary amount of spare parts shall be optimised in terms of defect repair readiness as well as servicing.
- The maintenance costs for an equipment location shall be optimised in the long term.
- The accumulated operating and maintenance experience shall be effectively utilised in the evaluation and planning of the condition monitoring and servicing/inspection programme.
- Justifications shall be recorded for later reassessments.
- The maintenance data systems shall be utilised effectively and "openness of data" shall be increased so that the information related to maintenance activities can be easily accessed and evaluated by the parties requiring them (operation, maintenance, engineering, safety, and others).
- The parties involved in maintenance activities shall be provided with more information on the significance of the functionality of the different equipment locations in terms of the facilities' safety and availability.

Posiva's maintenance is divided into three areas:

- The aim of preventive maintenance is to prevent equipment failures that reduce the facilities' availability and safety, to improve equipment reliability and to schedule the necessary maintenance actions as appropriate.
- Corrective maintenance restores the original condition of failed equipment.
- Improving maintenance includes the modifications and modernisations of equipment and systems.

The equipment in Posiva's nuclear facilities is divided into equipment ownership areas. For each of these, the appointed equipment owner is responsible for maintenance planning within their ownership area. Maintenance planning includes, among other things, the planning of the preventive maintenance and condition monitoring programmes and spare part planning for the equipment ownership area, establishing the need for equipment modifications and improvements, and maintaining and developing the preparedness for repairing defects.

The maintenance planning for equipment is based on the division of equipment locations into four maintenance classes. The maintenance class is selected on the basis of the significance of equipment failure in terms of the functionality of the system and the entire facility. The classification takes into account the significance of the equipment in terms of operational reliability and safety, as well as the maintenance costs. The maintenance class affects, among other things, the spare parts arrangements for the equipment location and the selection of preventive maintenance and condition monitoring tasks as follows:

- Class 1: the equipment shall be maintained in working order at all times
- Class 2: limited unavailability is allowed for the equipment
- Class 3: financially justified preventive maintenance is allowed for the equipment
- Class 4: no planned preventive maintenance is carried out on the equipment.

Planning of preventive maintenance

Preventive maintenance is divided into periodic maintenance, condition monitoring and periodic inspections.

The equipment owner is responsible for planning the preventive maintenance actions and programme for the equipment. The planning is based on the equipment's maintenance class, the preventive maintenance instructions and maintenance schedules from the manufacturer, and internal and external operating experience.

Preventive maintenance activities for the equipment are registered in the preventive maintenance data system (ENKKU). It is used in order to maintain the preventive maintenance programmes and to guide all the preventive maintenance work. The preventive maintenance programme for an equipment location is planned based on a maintenance analysis, so that maintenance actions can be focused for eliminating likely defects.

Evaluation of the maintenance programme

The adequacy of the programme is evaluated such that it ensures the reliability and defect repair readiness of the required equipment location and optimises the total costs for corrective and preventive maintenance of the equipment location. When assessing the maintenance actions for an equipment location, the ageing and wear phenomena of the equipment location shall be considered such that the operational reliability of the equipment locations remains on the desired level and any improvements can be implemented sufficiently in time.

RADIATION LEVELS AND RELEASES OF RADIOACTIVE SUBSTANCES ARE MONITORED

Comprehensive monitoring of radioactivity and dose rates will be implemented at the encapsulation plant and disposal facility. The radiation safety of the rooms at the encapsulation plant and disposal facility will be monitored by means of a room radiation measurement system. The monitoring covers all the rooms in which transport containers or final disposal canisters containing spent fuel are transferred, processed or stored. In addition, the fuel handling cell has its own, focused radiation measurement system. Furthermore, room monitoring includes some facilities relating to fuel handling processes, which are monitored in order to ensure the correct operation of the processes and the rooms' radiation safety. For the most part, the equipment used measures gamma radiation dose rate, but the system also includes other measurements. The system issues warnings and alarms for increased or excessive dose rates.

In addition to room monitoring, dedicated monitoring is implemented for the process systems that are the most important for radiation safety. The radioactivity and filtering of the handling cell ventilation is constantly monitored with radiation measurements. There is also continuous radioactivity monitoring of the exhaust air passed through the encapsulation plant's exhaust stack into the facility environment. Furthermore, the radioactivity contained in the encapsulation plant's radioactive water collection system is also monitored. It is expected that no radioactive waste or wastewater is generated at the disposal facility. The wastewater from the encapsulation plant's radiation controlled area will either be taken to the Olkiluoto nuclear power plant units for further processing or determined to be clean, cleared from regulatory control and pumped into the facility environment.

Equipment form the portable radiation measurement system is used for measuring radiation doses, dose rates and radioactivity at the encapsulation plant and disposal facility whenever the fixed radiation measurement system cannot be used for the task. The system also includes dosimeters for measuring the personnel's radiation doses and dose rates.

In order to ensure radiation safety monitoring, employees' personal dose and dose rate monitoring using portable dosimeters (TLD and electronic) is used in addition to permanent radiation measurement channels in area monitoring. This is done, for example, in locations where there is other reliable data (such as camera surveillance) available on the presence of a transport container or a final disposal canister (containing spent fuel), or where human presence simultaneously with a canister has been otherwise reliably prevented (locking of rooms), or the room's purpose of use does not pose significant work-related radiation safety risks to the users of the room. Even in this case, the processing of nuclear fuel in the room in question is allowed only if the room's fixed radiation measurement is operable.

Radiation dose rate monitoring in the vicinity of the encapsulation plant and disposal facility shall be carried out by expanding TVO's existing environmental dose rate measurement system. The system will be expanded by installing new measuring stations in the area of the encapsulation plant and disposal facility.

SAFETY CULTURE IS THE STARTING POINT OF POSIVA'S ORGANISATION

Posiva's organisational structure is described in Appendix 7 to this application: "Report on the expertise available to the applicant and the operational organisation of the nuclear facility".

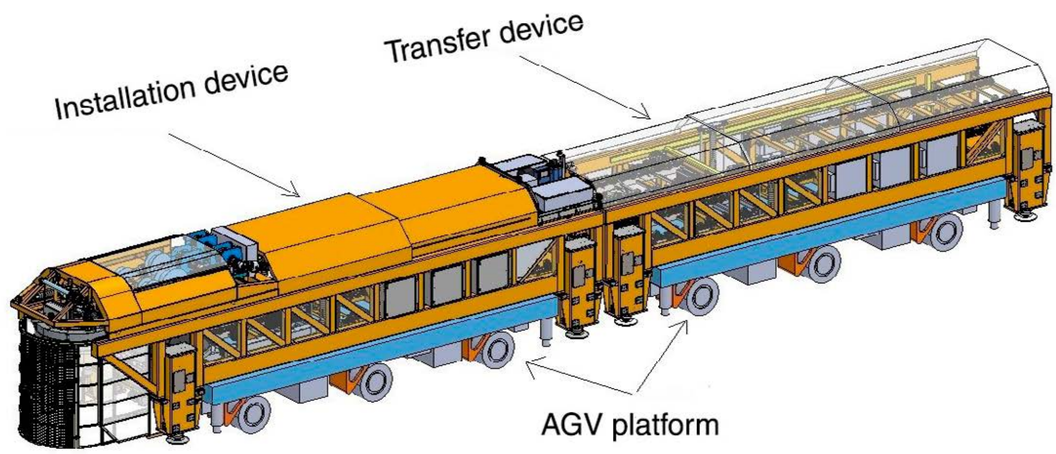
Posiva has adopted a well-developed safety culture. "A well-developed safety culture" refers to the way of thinking, attitude, way of acting and work atmosphere prevailing in the organisation which emphasise the prioritisation of the safety of the facility's operation and the safety-relevant aspects at all stages of operations. This, in turn, means safety awareness; high levels of professionalism; careful working practices; and vigilance and initiative to detect and eliminate safety hazards. When aiming for a good safety culture, the characteristics of the practical operations of an organisation implementing a good safety culture, defined by the International Atomic Energy Agency (IAEA), are used as guidelines.

- The objective of the management system is to ensure that nuclear safety and radiation safety are prioritised without exception, and that quality management requirements correspond to the safety significance of the activity and function. The management system must be assessed and developed systematically.
- For each function, it is necessary to identify the requirements significant for safety and describe the planned actions for ensuring that the requirements are met.
- Systematic practices must be used for identifying and correcting significant deviations.
- The licensee must commit and oblige their personnel as well as the suppliers, subcontractors and other partners who participate in functions affecting safety in the systematic management of safety and quality.
- The impacts on safety of significant organisational changes must be assessed in advance.
- Tasks that are significant in terms of safety shall be named.
- The licensee shall employ sufficient and competent personnel for ensuring the safety of the nuclear facility.
- The licensee shall have, as support for the responsible manager, a group of experts, independent of the other parts of the organisation, convening on a regular basis to handle safety-related issues and giving recommendations thereon if necessary.

PROCESS DESCRIPTION OF THE FINAL DISPOSAL ACTIVITIES

During the final disposal process, spent nuclear fuel is transferred from interim storage to the encapsulation plant to be packed into a final disposal canister and transferred to the disposal repository located at a depth of more than 400 metres. Globally unique technological solutions have been developed for the work stages related to the process.

Once the final disposal operations are under way, spent nuclear fuel is brought from interim storage to the encapsulation plant for packing inside final



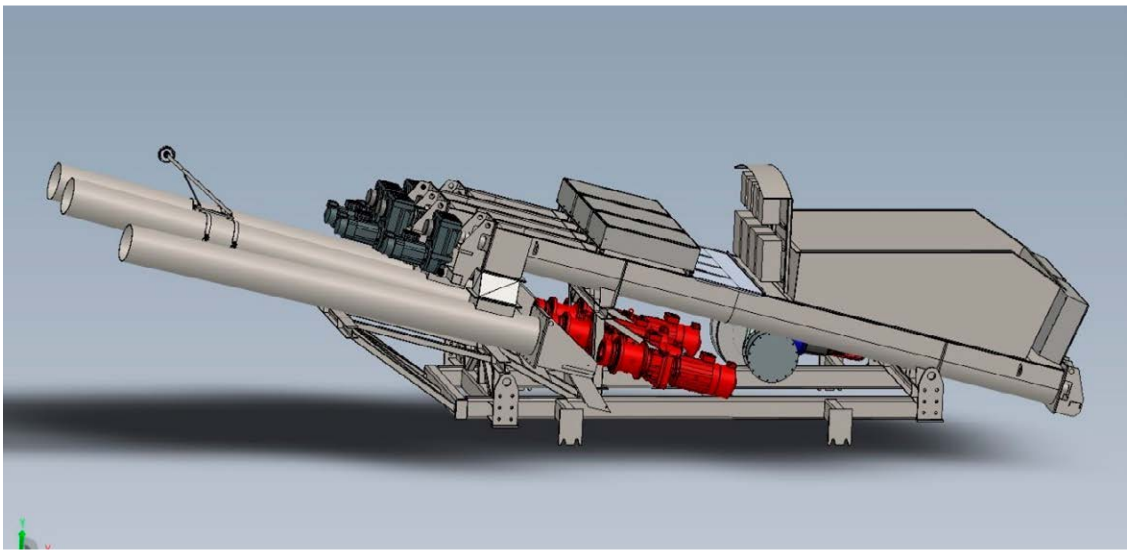
■ **Figure** 10. Buffer block installation system

disposal canisters made of copper and spheroidal graphite cast iron. The encapsulation plant is connected to the underground disposal facility via a canister lift, which transports canisters down to the underground reception station on the final disposal level at a depth of 430 metres. From there, they are transferred into deposition tunnels by using transfer and installation vehicles.

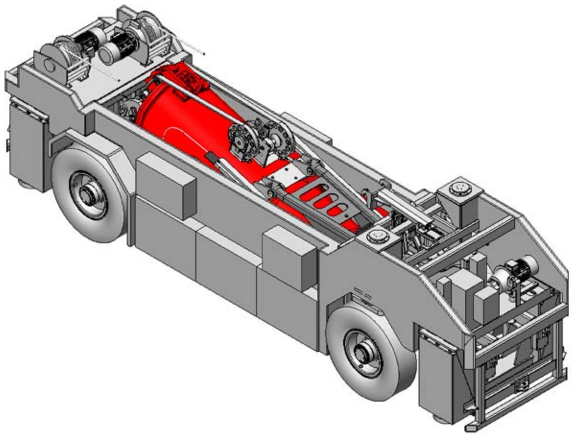
At the encapsulation plant, the final disposal canister is moved at the different work stages in the underground premises of the encapsulation plant. The spent nuclear fuel is loaded into final disposal canisters in a fuel handling cell, which has approximately 1.3 m thick concrete walls. Once all the fuel assemblies have been moved inside the canister, it is filled with argon gas and sealed tightly with the canister's inner steel lid. The canister's topmost copper lid is sealed by means of friction stir welding in the welding cell, and the weld seam tightness is ensured visually as well as with eddy current and ultrasonic inspections. Friction stir welding, selected for welding, creates a joint on the copper lid such that the integrity of the joint is equivalent to the integrity of the canister shell. Posiva has developed the method together with SKB, which is responsible for the final disposal of spent nuclear fuel in Sweden.

THE DEPOSITION HOLES ARE BORED INTO THE BEDROCK

The Deposition Hole Boring Machine (DHBM) is a piece of the special equipment developed for final disposal. There are requirements specified



■ **Figure** 11. Tunnel backfill installation equipment.



■ **Figure** 12. Canister transfer and installation vehicle. Marked in red in the figure is the radiation shield inside which the final disposal canister is transported.

for boring the holes in order to ensure that the holes are suitable for final disposal. It is important that the measured centre point of the 8 m deep deposition hole does not, at any depth, deviate more than 25 mm from the vertical centre line between the start and end points.

THE DEPOSITION HOLE AND TUNNEL ARE CLOSED USING A BUFFER AND BACKFILL

Underground final disposal involves various pieces of clay component transfer and installation equipment: AGVs (automated guided vehicles), the buffer installation system (BIS) and the granular backfill installation system (GBIS). AGVs, autonomously navigating and moving carriages, are used as the vehicle technology in the installation systems for both the buffer and deposition tunnel backfill. The machines are designed to install the buffer and tunnel backfill according to the requirements. Among other things, the requirements are used for ensuring long-term safety.

Buffer block installation system

The buffer installation machine is used for installing the buffer blocks in the deposition hole. Buffer installation is completed in two parts. At the first stage, solid blocks are installed on the bottom of the hole. Then, blocks with an opening in the middle for the canister are installed. After the installation of the canister, the topmost buffer blocks are installed on top of the canister. Furthermore, both of these stages involve filling any empty space with fine granular bentonite in order to create a tight buffer. Installing the buffer around a final disposal canister is a precise task from start to finish.

Tunnel backfill installation system

In 2019, Posiva decided that the deposition tunnels are filled with a granular mixture comprising crushed bentonite pellets of varying sizes. Previously, the idea was to use blocks and pellets made of bentonite clay for the tunnel backfill. However, this approach was deemed to be challenging to implement, which is why Posiva started to investigate an alternative that would be just as safe but financially more affordable and more industrial in terms of the manufacture and installation of materials.

The idea for the final disposal backfill solution is derived from the Swiss final disposal company NAGRA's buffer solution surrounding the canister. A granular backfill solution ensures the functionality of the buffer surrounding the canister such that the buffer cannot rise from around the canister into the deposition tunnel.

The main task of the tunnel backfill installation equipment is to transfer the granular material into the deposition tunnel by filling the tunnel from the floor to the ceiling. During tunnel backfilling, the equipment moves slowly in reverse until the entire tunnel is filled.

Canister transfer and installation vehicle

The canister transfer and installation vehicle (KSAA) is the only system in the underground final disposal process with a safety classification (SC3). Its purpose is to transport final disposal canisters containing spent nuclear fuel and place them inside deposition holes. The canisters are transported inside a 150 mm steel radiation protection tube. Furthermore, the inside of the tube has a PE plastic coating that absorbs neutron radiation.

The dead weight of the equipment is 90 tonnes, but with a canister on board, its weight rises up to 120 tonnes.

The operation of the canister transfer and installation vehicle begins when a copper canister from the canister storage is lifted inside the radiation protection tube. Before departure, the tube is rotated horizontally, after which the canister is transported into the desired tunnel. Finally, the vehicle is balanced above the correct hole, and the canister is lowered in the middle of the buffer blocks.

THE NUCLEAR WASTE FACILITIES HAVE EMERGENCY AND SECURITY ARRANGEMENTS IN PLACE

THE EMERGENCY PREPAREDNESS ARRANGEMENTS MUST BE PLANNED IN CASE OF ACCIDENTS

The Radiation and Nuclear Safety Authority defines the overall emergency preparedness arrangements for nuclear power plants and supervises the activities.

Emergency preparedness events are divided into three categories depending on their severity and manageability: alert, site area emergency and general emergency. Posiva's final disposal operations also involve preparing for a possible emergency preparedness event. However, the occurrence of such an event is very unlikely. The category depicts the severity and manageability of the event and the scope of the actions according to the preparedness plan initiated by the event. Each emergency preparedness event is separately defined as belonging to one of the above categories at each point in time. Categories may change as the situation develops.

OLKILUOTO USES COMMON EMERGENCY PREPAREDNESS PROCEDURES

The emergency preparedness procedures make up TVO Group's emergency preparedness plan, which covers TVO's nuclear power plants as well as Posiva's nuclear facility. The purpose of the emergency preparedness plan is to prepare for possible radiation accidents threatening the facility personnel, the environment and the facility itself, as well as their mitigation. The emergency preparedness plan has been created to guide the activities of TVO Group's organisation in order to ensure that the necessary actions in the Olkiluoto area are carried out.

The nuclear facility and the nuclear power plants (Posiva, OL1, OL2, OL3) take care of implementing the emergency preparedness arrangements in the Olkiluoto area and maintaining the Olkiluoto emergency preparedness organisation in accordance with the emergency preparedness plan. In case of an accident, the task of the emergency preparedness organisation is to:

- report the accident
- participate in rescue and extinguishing activities in the Olkiluoto plant area
- when necessary, warn the population in the vicinity of the plant area (0–5 km)
- participate in radiation measurements in the plant area and its immediate surroundings
- provide information on how the accident develops, issue recommendations for actions and provide other expert assistance
- when necessary, carry out an emergency evacuation in the plant area, supported by the rescue organisation.

THE OLKILUOTO EMERGENCY PREPAREDNESS ORGANISATION HAS DEFINED RESPONSIBILITIES

In case of accidents, the Group's emergency preparedness organisation is responsible for emergency preparedness activities – the actions based on the emergency preparedness plan. The emergency preparedness organisation has been formed starting from the normal line organisation presented in the organisation manual. Whenever possible, the responsibility areas of personnel have been retained in order to ensure smooth transitioning to performing the actions required by the accident conditions.

THE EMERGENCY PREPAREDNESS ORGANISATION TRAINS REGULARLY

Posiva's emergency preparedness arrangements are part of the TVO Group's emergency preparedness arrangements. The group-level emergency preparedness plan is also followed regarding Posiva's emergency preparedness arrangements. The emergency preparedness organisation has been supplemented with representatives from Posiva's Support Group in order to ensure that the emergency preparedness organisation is able to function also in accidents that originate at Posiva.

The planned emergency preparedness is

achieved and maintained through basic and advanced training, emergency preparedness exercises and public information. The responsible Plant Manager/Emergency Preparedness Manager is responsible for ensuring that the procedures in the emergency preparedness plan are followed and the functions are implemented. The person responsible for the emergency preparedness arrangements is responsible for maintaining the readiness to carry out the emergency preparedness plan, acquiring necessary equipment, arranging training sessions and handling the practical arrangements of emergency preparedness exercises.

ACTIVITIES IN AN EMERGENCY PREPAREDNESS EVENT ARE BASED ON IDENTIFIED FUNCTIONS

Activities in an emergency preparedness event are based on identified functions. The functions identified in an emergency preparedness event are:

- Declaring an emergency preparedness event
- Alerting
- In-house personnel
- Alerting the authorities
- Alerting the nearby areas
- Mustering, situational awareness
- Accident management
- Evacuation of facility area
- Environmental monitoring
- Assisting procedures
- Security arrangements
- Communication
- Restoring the facility state
- Documentation

THE EMERGENCY PREPAREDNESS EVENT IS CANCELLED IN A CONTROLLED MANNER

The restoration of the state of the facility and environment is immediately started once the accident is under control. The measures are led by the Emergency Preparedness Manager, assisted by the support group. The normal line organisation functions are resumed later. The requirement for cancelling an emergency preparedness event is that the facility is in a safe state, releases do not exceed the limits for normal operation and post-accident procedures are initiated.

The post-accident procedures include at least the following:

- analysing the changes to the nuclear facility's structures, equipment or systems that affect maintaining the facility in a safe state
- any measures necessary for the management of radioactive substances
- assessment of radiation doses caused by the accident
- determining the causes of the event and preparing a report on the event.

Furthermore, cleaning procedures must be initiated and waste management carried out when necessary. In case the rescue activities continue after the nuclear facility's emergency has been cancelled, preparations shall be made for co-operation similar to that during the emergency. Radiation dose limits for normal operation are adhered to in decontamination tasks whenever possible. The analysis of the post-accident situation and decision-making on further measures are carried out in co-operation with STUK.

THE NUCLEAR WASTE FACILITIES HAVE PROPER SECURITY ARRANGEMENTS IN PLACE

The security arrangements for the encapsulation plant and disposal facility, transports and transfers are based on the Radiation and Nuclear Safety Authority (STUK) Guides YVL A.11 and A.12, STUK Regulation STUK/Y/3/2020 on the Security in the Use of Nuclear Energy, design basis threat, Nuclear Energy Act and collaboration with the authorities.

Posiva's nuclear facilities are located in the Olkiluoto power plant area, which provides the advantage that a great deal of the security arrangements are shared with TVO.

The purpose of the security arrangements is to detect and prevent unlawful activities, thereby ensuring, on their part, the safe operation of the facilities. This is achieved through administrative actions and structural solutions, among other things.

The adequacy and effectiveness of the security arrangements is tracked, involving the police authority if necessary, and based on this tracking the security arrangements are constantly maintained and developed in order to ensure a sufficient level of security arrangements under all conditions.

WORKING AND DOING BUSINESS AT THE NUCLEAR WASTE FACILITY IS SUBJECT TO PERMITS

An access permit is required for working at the nuclear facilities, and the employee must pass a security clearance in order to receive a permit. Any other business and visits are carried out under a visitor permit. Issuing a visitor permit involves verifying the visitors' identity and the purpose of the visit. All person and goods traffic, employees and visitors alike, is monitored. This is implemented through radioscopy and metal detectors. The legality of goods transports is verified and the transports are examined. Furthermore, alcohol and drug tests are randomly carried out on persons entering the area.

THE SECURITY PERSONNEL IS TRAINED FOR THREATENING SITUATIONS

The nuclear facilities have security personnel with the appropriate training for threatening situations as well as normal security monitoring. Under the Nuclear Energy Act, the security personnel have special rights to use force, which may be applied in threatening situations based on the principle of least possible harm. If there is a risk of a threatening situation or if a threatening situation occurs, the security personnel will follow the instructions by the alarm centre until the police authority announces to take responsibility for managing the situation. After this, the security personnel shall follow the instructions by the police authorities.

THE IMPLEMENTATION OF SAFETY INVOLVES INTERNATIONAL OBLIGATIONS

Posiva's operations include complying with international contracts in terms of nuclear safeguards, among other things. In accordance with the Euratom Treaty, the European Commission must be provided with the necessary information concerning an investment project for the construction of a nuclear facility such that the Commission may evaluate the impacts from the project. Furthermore, a so-called environmental report must be made to the European Commission regarding the environmental impacts relating to the operation of the nuclear facility. Based on the information provided in the environmental report, an international team of experts evaluates the possible impacts from the nuclear facility that extend to the area of neighbouring states.

Nuclear safeguards based on international agreements are implemented by the International Atomic Energy Agency IAEA and Euratom (in practice the European Commission). For this purpose, basic technical data concerning the facilities must be provided so that Euratom and the IAEA can plan nuclear safeguards concerning the facilities. The nuclear facility's operator must enable access by international organisations' inspectors to the facilities. The IAEA and Euratom carry out verification of design information, extraordinary inspections and so-called short-notice surprise inspections in order to verify the peaceful use of the nuclear materials present at the facilities. The operator must have in place a nuclear materials accounting and reporting system that allows for tracking the amounts and locations of nuclear materials at the facilities. This information is reported to the European Commission on a monthly basis.

One special characteristic of the final disposal of spent fuel is that the nuclear material placed in final disposal will be permanently out of reach of conventional surveillance. Therefore, it is particularly necessary to ensure the amount and type of the fuel placed in final disposal before the final disposal canister is sealed. The implementation of nuclear safeguards, obligations, accounting and reporting are instructed in the nuclear safeguards manual approved by the Radiation and Nuclear Safety Authority.

The final disposal of spent nuclear fuel or highly

THE HISTORY OF FINAL DISPOSAL IN FINLAND

active reprocessing waste in facilities excavated deep in bedrock was brought up as a feasible alternative already in the 1950s. The considered alternatives to geological final disposal were found to have significant problems in terms of feasibility and safety. Supervised long-term storage is only a temporary solution, after which final disposal is required sooner or later. Geological final disposal does not require surveillance or maintenance and, thereby, would not cause unnecessary strain on future generations. The most common solution-in-principle developed for final disposal was a concept in which waste packages would be placed in premises excavated or bored deep in the bedrock (at a depth of 0.5–1 km).

Analyses on the safe final disposal of spent nuclear fuel began already in the 1970s. In 1978, Teollisuuden Voima Oy (TVO) and Imatran Voima Oy (IVO) issued a joint study on nuclear waste, whose purpose was compiling the principles and solutions regarding the management of spent nuclear fuel, reprocessing waste and operating waste. As a final disposal solution for reprocessing waste and spent nuclear fuel, they presented a model that was based on the first version of the KBS concept, which had been developed in Sweden earlier.

Finland specified the guidelines and schedule targets for nuclear waste management in 1983 when the Government presented the principle programme for nuclear waste management and its schedule targets. In 1994 the Nuclear Energy Act was enacted, stipulating that nuclear waste must be processed, stored and placed in final disposal within Finland and that no nuclear waste from other countries may be imported to Finland. Posiva Oy was established in 1995 to look for a solution for this requirement.

The research on the final disposal site began already in the early 1980s after the Finnish Government issued a decision-in-principle regarding the final disposal of spent nuclear fuel. The decision outlined the final disposal goals and schedule. The first safety analysis in Finland was TVO-82 (Anttila et al. 1982). It was carried out before the site selection research and was related to the phase of general geological research, which determined the suitability of Finnish bedrock for the final disposal of spent nuclear fuel. In 1985, at the site selection stage, the following safety analysis, TVO-85 (Peltonen et al. 1985) was carried out.

After the initial studies, site studies were conducted in Finland in the 1990s. From several different alternatives, it was decided that more detailed studies would be carried out at Olkiluoto in Eurajoki, Kivetty in Äänekoski, Romuvaara in Kuhmo and Hästholmen in Loviisa. In addition to geological studies, the research at these locations included the socio-economic effects from final disposal and examined the logistics of spent nuclear fuel and the infrastructure of these areas. After the studies, Loviisa and Olkiluoto, Eurajoki were chosen for further examination. The residents of these locations were used to Finnish people being responsible operators in the nuclear power industry. Therefore, the idea of final disposal was more natural at these locations.

After five locations (incl. Olkiluoto) had been chosen for site studies, the TVO-92 safety analysis (Vieno et al. 1992) was prepared. Four years later, the TILA-96 safety assessment (Vieno & Nordman 1996) considered three disposal sites: Kivetty, Olkiluoto and Romuvaara. Later, Hästholmen was included as a new location (TILA-99, Vieno & Nordman 1999). TILA-99 continued and updated the work carried out in TVO-92 and TILA-96 for evaluating long-term safety. The conclusion was that final disposal can be implemented in compliance with the radiation safety regulations on any of the four study sites.

The KBS-3 concept, which is mainly equivalent to the current one, was developed in Sweden in the 1990s. It features a cast-iron inner canister with a 5 cm thick copper shell around it; the canisters are placed in deposition holes surrounded by a bentonite clay buffer, and a bentonite backfill is installed in the deposition tunnels. The concept that Posiva presents as its reference solution in connection with the operating licence application is based on the KBS-3 concept, with changes made in the manufacturing technology of the

Figure 13. The Olkiluoto bedrock is one of the most extensively researched locations in Finland; this has proven the suitability of the bedrock for final disposal.

engineered release barrier components and shape of filling materials, among other things.

The turn of the millennium was an important milestone in the planning of the final disposal of nuclear fuel with Olkiluoto, Eurajoki being chosen as the final disposal site. As the Government's decision-in-principle required more thorough examination of the bedrock, Posiva had to reach the final disposal depth. At the time, it was considered whether the level deep in the bedrock should be accessed through shafts, a driving tunnel or a combination thereof. Eventually, the construction of ONKALO was started as a combination of shafts and a driving tunnel in 2004.

Studies relating to the final disposal site selection have been implemented at various stages, from broader site selection studies to detailed site studies at Olkiluoto. After the establishment of Posiva (1995) and the decision-in-principle (2001) choosing Olkiluoto as the final disposal site, the aim of the site studies has been verifying the suitability of Olkiluoto bedrock for use in final disposal. In the past 20 years, the studies have focused on Olkiluoto Island. Their aim has been to verify Olkiluoto's suitability for final disposal, and the studies have been able to confirm that the Olkiluoto bedrock is suitable for final disposal.

Posiva's final disposal system is based on a

According to the Nuclear Energy Act, nuclear waste generated in Finland must be disposed of in Finland, and nuclear waste generated elsewhere cannot be imported into Finland

THE FINAL DISPOSAL SYSTEM MAKES SAFE FINAL DISPOSAL POSSIBLE

principle solution known as KBS-3V, in which the canisters are placed vertically in relation to the ground surface (vertical deposition solution) (Figure 14). This solution has been developed by Svensk Kärnbränslehantering AB (SKB), the company responsible for Swedish nuclear waste management. The long-term safety concept of the final disposal solution is based on the multi-barrier principle, i.e. several redundant release barriers, such that the reduced performance of any single release barrier does not compromise long-term safety.

The engineered release barriers in the final disposal system are the tight iron–copper canister, the bentonite buffer surrounding the canister, the tunnel backfill material made of expanding clay and the closure structures of tunnels and facilities. The surrounding bedrock acts as a natural release barrier (Figures 14 and 15).

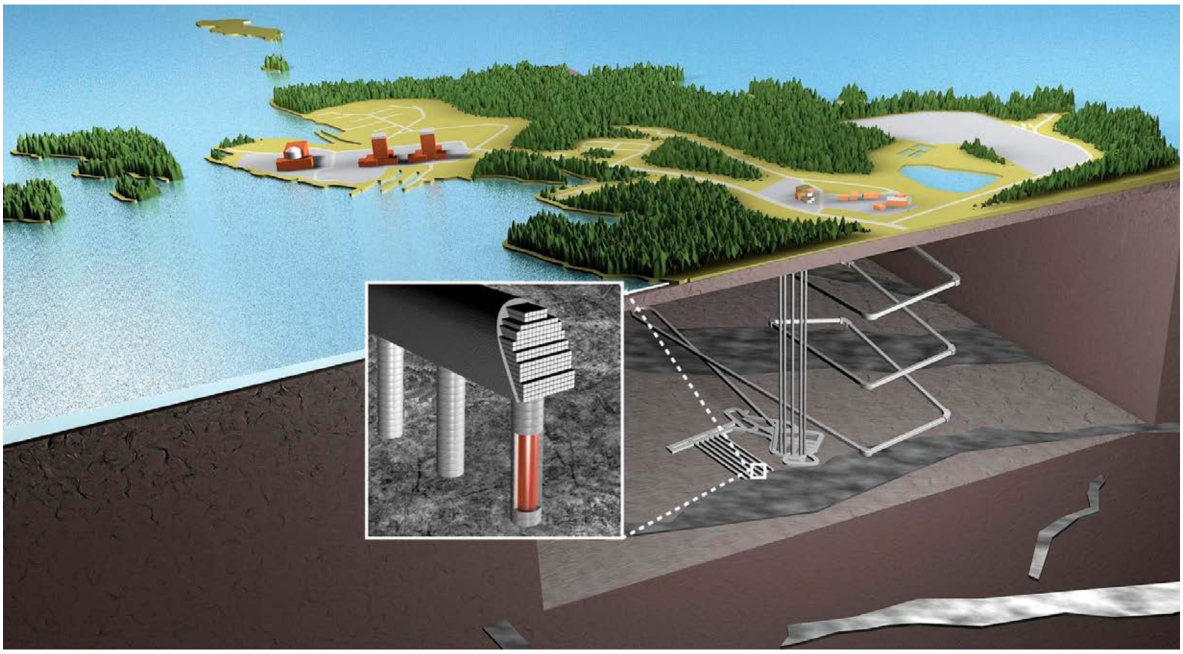


Figure 14. The final disposal canisters are placed vertically in relation to the ground surface. The solution is titled KBS-3V.

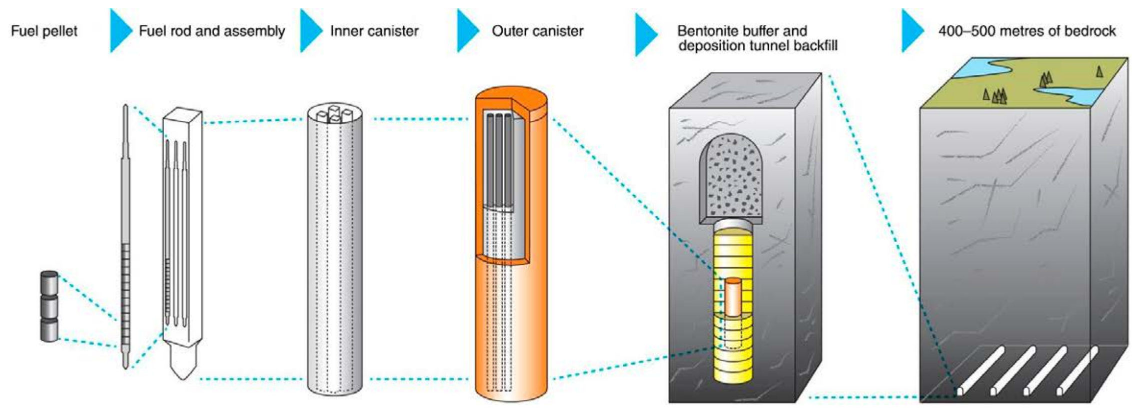


Figure 15. The different parts of the final disposal system according to the multi-barrier principle.

THE PROPERTIES OF SPENT NUCLEAR FUEL CONTRIBUTE TO THE FINAL DISPOSAL

The ceramic form of the fuel is one release barrier. The uranium inside gas-tight metal rods is a solid material that dissolves poorly in water, which slows down the release of radioactive substances. This property supports the realisation of long-term safety in the event that the tightness of the final disposal canister is compromised.

Nuclear fuel becomes highly radioactive during the fission reaction that occurs in electricity production. Different materials can be used for shielding against radiation. A few years after spent fuel is removed from the reactor, it is transferred to interim storage. There, fuel is stored in pools of water. It is safe to access the edge of the pools, as the 8 m of water above the fuel assemblies stops the radiation coming from them. At the time of final disposal, a couple of meters of rock will completely stop the radiation from the assemblies.

Spent nuclear fuel is highly radioactive immediately after use but, after a year, its radioactivity is reduced to a hundredth. The radiation from spent nuclear fuel is quickly reduced in the first decades following its removal from the reactor. When the fuel is being placed in final disposal after 40 years, only a thousandth of its original radioactivity remains. At the time of the final disposal, the canister walls and a couple of metres of rock are enough to stop the radiation from the spent fuel completely. After this, the reduction of radiation continues such that, within a thousand years, the radioactivity will have reduced to approximately a thousandth from the level during the first year of this period. At the same time, the radiation level on the canister surface will have reduced to approximately a hundredth of the level at the time of its final disposal. The radioactivity of spent nuclear fuel placed in final disposal will have reduced to the level of a rich uranium ore deposit within 250,000 years.

Few of the radioactive substances contained in spent nuclear fuel have a very long life, and they require long-term isolation from living nature. Therefore, the canisters used in the final disposal solution are designed such that they will maintain their tightness in their place of final disposal for such a long time that the radioactivity in the spent fuel has reduced to a level that is not harmful to the environment and people.

The four reactors in Loviisa and Olkiluoto have, so far, generated approximately 2,440 tonnes of uranium (tU) of spent fuel and approximately 15,000 fuel elements. As of early autumn of 2021, there were 2,380 tonnes of highly active nuclear waste in Finland, and an additional 65 tonnes are generated annually; a total of approximately 100 tonnes are generated annually after the start of the OL3 plant unit.

SPENT NUCLEAR FUEL IS COOLED IN INTERIM STORAGE UNTIL IT IS SUITABLE FOR FINAL DISPOSAL

The service life of a fuel element is approximately 5 years, and some of the fuel is replaced once per year during an annual outage. The spent fuel is cooled in plant pools for a few years, after which it is transferred to the KPA storage for interim storage in pools of water. The minimum cooling time of spent nuclear fuel at the KPA storage is approximately 20 years, but the average cooling time is more than 30 years.

A fuel element comprises the following components:

- fuel rod fuel pellets (UO2),
- the fuel rod cladding and possible flow channel/case (Zr alloys),
- other support structures, incl. intermediate supports and end pieces.

In addition to the above, for example concerning the EPR fuel, the control rods from the control rod element will be placed in final disposal. More information on spent nuclear fuel is in Appendix 4 “Nuclear Waste Management” to the operating licence application.

In addition to the above, for example concerning the EPR fuel, the control rods from the control rod element will be placed in final disposal. More information on spent nuclear fuel is in Appendix 4 “Nuclear Waste Management” to the operating licence application.

There are three different fuel types in Finland: BWR, VVER and EPR. The major differences between

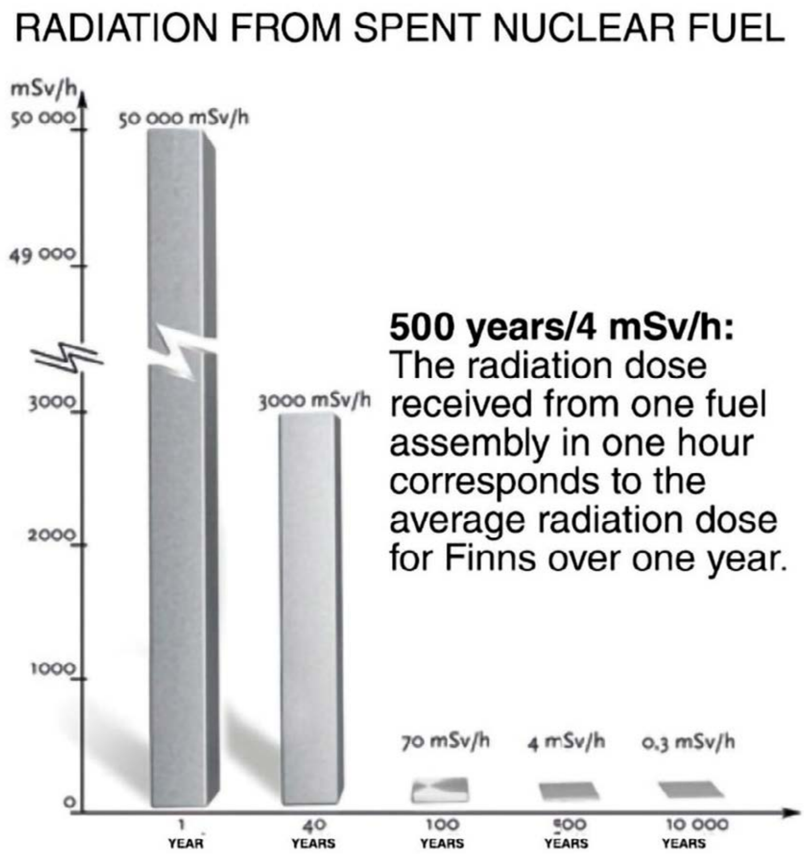


Figure 16. A graph depicting the radiation of nuclear fuel over time. Due to radiation, spent nuclear fuel is placed safely in final disposal in bedrock.

the types are the uranium weights, total weights, dimensions (length and cross-section), shape of fuel element and number of fuel rods. These types share in common the uranium oxide (UO2) of the fuel matrix and, thereby, the generation of decay heat and radiation is very similar between the different fuel types. Radioactivity is increased primarily by fission products, whose radioactivity is quickly reduced already during the period when the spent fuel is stored in the reactor hall water pools. For example, strontium and cesium have a half-life of approximately 30 years. Iodine isotopes have a half-life of hundreds of thousands or millions of years.

The final disposal solution must be safe because it will take approximately 200,000 years until the radioactivity of the waste has reduced to the level of natural uranium.

LONG-TERM SAFETY IS ENSURED THROUGH ENGINEERED RELEASE BARRIERS

The final disposal canister is the most important release barrier

The final disposal canister comprises a cast-iron insert and a copper outer shell. The purpose of the insert is to bear the mechanical load that focuses on the canister assembly, and the purpose of the copper outer shell is to isolate the spent fuel from its surroundings and withstand the conditions prevailing in the disposal repository over a long time. The corrosion resistance of the canister is ensured through component material selections and by verifying the compatibility of the canister and the other engineered release barriers in the entire final disposal system. The mechanical stresses focusing on the canister, such as creep, are inspected taking into account the different possible load scenarios. In final disposal, the different review periods involve different load scenarios focusing on the canister. Mechanical as well as chemical load scenarios are reviewed in anticipated conditions and alternative developments, and the review covers

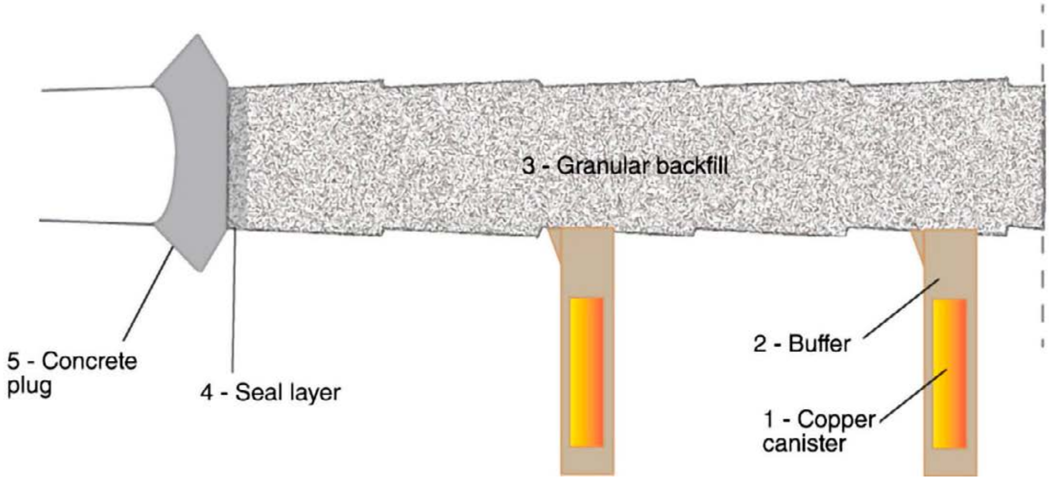


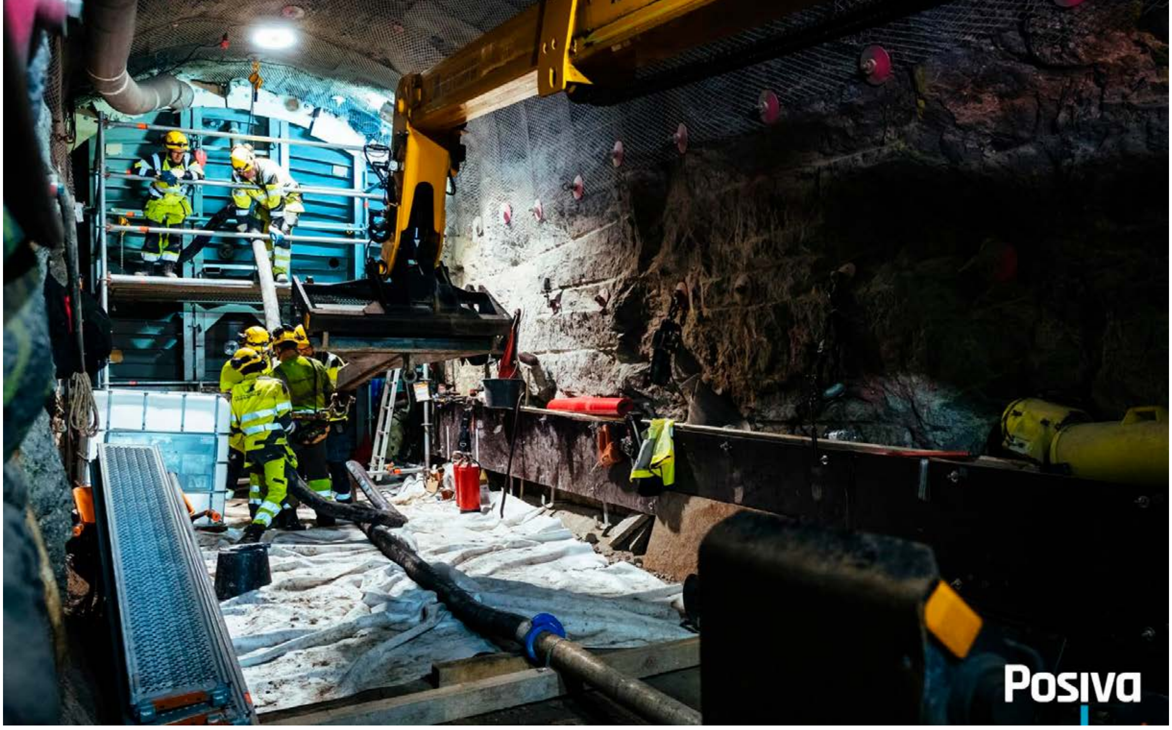
Figure 17. Engineered release barriers: 1 - Final disposal canister, 2 - Buffer, 3 - Backfill (4 - Sealing layer is part of the backfill), 5 - Deposition tunnel end plug (not considered to be an engineered release barrier).

Figure 18. An actual size final disposal canister is available for viewing at the Olkiluoto visitor centre.

the combined effects from different loads. The analyses involve experimental work, calculations and different simulations. Natural analogies are also utilised for justifying the long-term performance of the engineered release barriers.

The final disposal canister is closed by welding a lid and bottom onto the copper tube. The welding is subject to equivalent experimental work and analyses in order to ensure and demonstrate the long-term safety of the canister closure.

In canister production, quality is ensured through a comprehensive inspection plan. The inspection plan covers the phases from canister component production to installation. The inspection plan is followed when ensuring the compliance of the canister components and the canister assembly and the acceptability of installation.



■ **Figure** 19. Posiva has studied and tested the construction of the final disposal system for several years at Onkalo.

The buffer helps the final disposal canister to maintain its tightness

The purpose of the buffer is to keep the canister in place in the deposition hole, seal the canister's surroundings in the deposition hole and act as an engineered release barrier that supports the canister's safety functions with its chemical and mechanical properties. The buffer reaches its desired performance once it absorbs water from the surrounding bedrock and expands due to the water. Most of the buffer material is bentonite, which consists of an expanding clay mineral.

The long-term performance of the buffer is ensured by manufacturing and installing compliant buffer components in accordance with the initial state criteria. The establishment of the initial state and compliance with requirements shall be ensured according to the buffer inspection plan.

The backfill supports conditions favourable to the final disposal system

The purpose of the backfill is to keep the buffer in the deposition hole and to fill and seal the excavated open area in the deposition tunnel. In terms of chemical properties, the backfill is similar to the buffer in that it does not have a harmful effect on canister corrosion and it helps minimise the amount of harmful substances reaching the canister due to the material's tightness. Similar to the buffer, the performance of the backfill is based on the expansion of clay material due to water. The backfill material is also mainly composed of expanding clay minerals.

The compliant establishment of the backfill initial state is ensured with the inspection plan, as with the other engineered release barriers. In the initial state, the backfill clay is composed of a bulk mass with a certain grain size distribution. Compliance is based on achieving a defined density window, and quality assurance during installation is based on tracking the installed backfill mass.

THE OLKILUOTO BEDROCK IS SUITABLE FOR FINAL DISPOSAL

The Olkiluoto bedrock has been studied for decades, and its suitability for the final disposal of spent nuclear fuel has been demonstrated. Final disposal will take place in the Olkiluoto bedrock at a depth of approximately 430 metres.

The safety function of the bedrock is:

- separating the spent fuel disposal repository from the surface environment and the normal living environment of humans, plants and animals, limiting the possibility of human intrusion and isolating the disposal repository from the changing conditions of the ground surface.
- providing favourable thermal conditions for the disposal repository.
- providing mechanically stable and hydrologically and geochemically favourable conditions for the engineered release barriers.
- restricting the travel of harmful substances potentially released from the disposal repository.

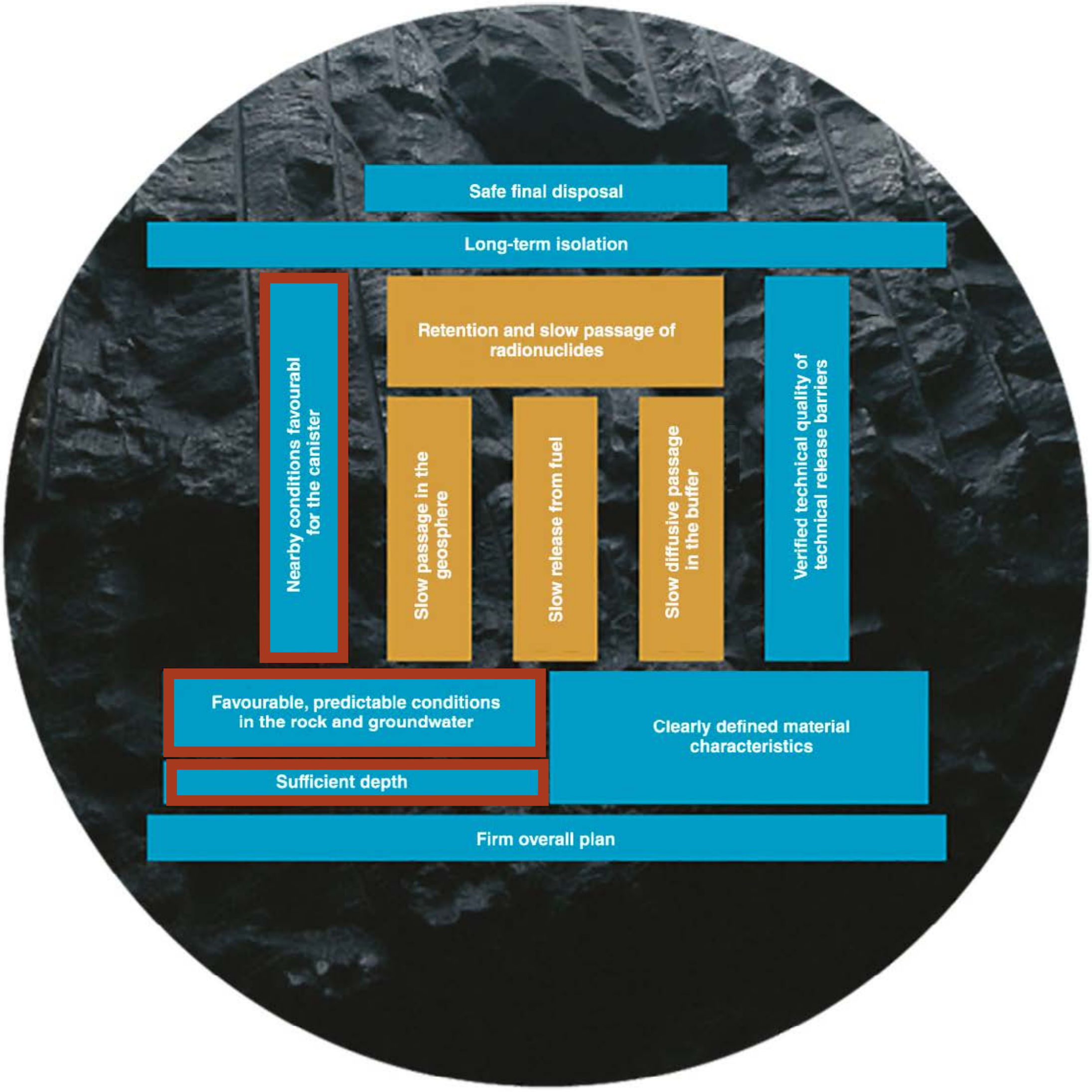


Figure. 20. The safety concept for the KBS-3 final disposal system in a crystalline bedrock. The blue columns and blocks describe the primary safety functions. The yellow columns and blocks describe the secondary safety functions, which become important in events where radionuclides may be released from the canister. The red boxes indicate the role of the bedrock in the safety concept.

Figure 21. The suitability of the rock spaces guides the large-scale positioning and becomes more specific, ultimately determining the suitable locations for deposition holes.

The Rock Suitability Classification (RSC) creates a link between long-term safety and planning by providing information on the rock volumes suitable for construction in terms of long-term safety for use in planning, thereby guiding the construction and positioning of the disposal repository.

Rock Suitability Classification:

- Utilises the latest available research data and models
- Generates suitability assessments that serve as initial data in the planning of premises and decision-making
- Progresses in stages and becomes more specific as the planning and construction of the premises advances from one stage to the next

Posiva has also identified four functions critical for long-term safety in relation to the construction of the disposal facility:

1. Management of leakage water allows for favourable environmental conditions

The construction of underground premises creates a disturbance in the groundwater conditions of the surrounding bedrock. In terms of leakage water management, limit values are specified for the measurement results and the technical implementation of leakage water management such that long-term safety will not be compromised based on the modelling reviews. The objective of leakage water management is maintaining the final disposal site's safety functions relating to the groundwater environment, i.e. allow for favourable and predictable chemical and hydrogeological conditions for the EBS components.

2. The management of safety-classified materials ensures the functionality of the release barriers

Safety-classified materials refer to all materials used in underground construction and other operations that do not belong to the engineered release barriers (final disposal canister, the buffer material surrounding the canister in the deposition hole and the deposition tunnel backfill material) or the natural release barrier of the KBS-3V multi-barrier principle. The purpose of the management of safety-classfied materials is ensuring that the engineered release barriers function as intended.

3. The management of the excavation damaged zone maintains the long-term safety of the bedrock

Rock excavation creates a damaged zone on the surface of the bedrock. The formation of this zone must be understood and managed such that excavation does not compromise the long-term safety of final disposal and that the natural conditions of the bedrock remain suitable for final disposal. This zone is referred to as "Excavation Damaged Zone" (EDZ).

4. Drilling and boring management prevents the formation of new routes leading to the ground surface

Holes created from underground or from the ground surface may possibly create a flow route between the disposal repository and the ground surface either directly or via water-conducting structures penetrated by the holes and the disposal repository. Therefore, all holes within the final disposal site that extend more than 5 m away from excavated spaces, or spaces to be excavated, and reach a depth of more than 30 m in the bedrock are processed via a separate long-term safety procedure. This ensures that no new flow routes that could compromise long-term safety are formed.

For the purpose of tracking the long-term development of Posiva's final disposal site and the disposal facility, the Olkiluoto final disposal site monitoring programme is carried out.

The bedrock of Olkiluoto has been found to be safe for final disposal

THE SUITABILITY OF THE FINAL DISPOSAL SITE FOR FINAL DISPOSAL HAS BEEN VERIFIED THROUGH RESEARCH

THE FINAL DISPOSAL SITE STUDIES DESCRIBE THE PAST AND FORECAST THE FUTURE

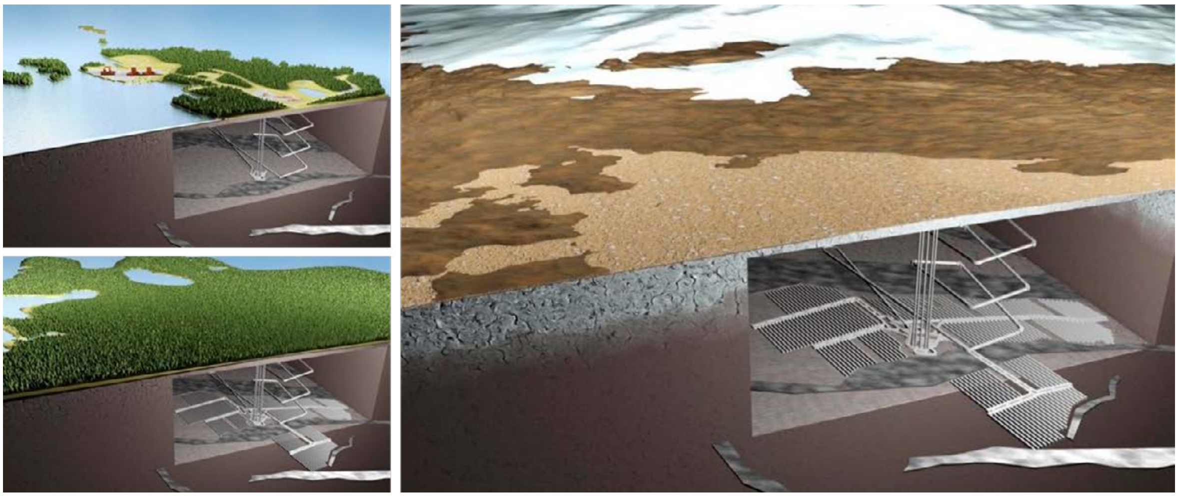
The research on the final disposal site began already in the early 1980s after the Finnish Government issued a decision-in-principle regarding the final disposal of spent nuclear fuel. The decision outlined the final disposal goals and schedule. Studies relating to the final disposal site selection have been implemented at various stages, from broader site selection studies to detailed site studies at Olkiluoto. After the establishment of Posiva (1995) and the decision-in-principle (2001) choosing Olkiluoto as the final disposal site, the aim of the site studies has been verifying the suitability of Olkiluoto bedrock for use in final disposal. After 2004, when the excavation of the research tunnel (ONKALO) was started, the research has focused on a more detailed level on determining the properties of the site for the design and construction of the disposal facility and for the purposes of the safety case. ONKALO has also enabled the testing of the final disposal technology deep in the bedrock at the final disposal depth of approximately 430 m. The construction of the research tunnel was completed in 2012, and it is now part of the disposal facility. After the construction licence was issued (2015), in the phase preceding the operating licence application, the understanding of the Olkiluoto site has been deepened and expanded through additional research and site modelling. In addition to conventional site studies performed overground and from a tunnel, research data on the final disposal site has been produced for the needs of the Rock Suitability Classification (RSC) and as part of the Olkiluoto research and monitoring programme (described hereinafter).

Research relating to the final disposal site is carried out in different fields at the site scale and on a more detailed level. The geological studies are focused on the properties of the bedrock, such as the rock types, bedrock fissures and fracture zones. Geophysical research provides information on the physical properties of the bedrock, such as electrical conductivity and magnetic properties. Rock mechanics examines the mechanical properties of the bedrock, such as the state of strain and the thermal conductivity properties of the bedrock. In terms of hydrogeology, the focus is on the occurrence of groundwater on the ground surface and in the bedrock, groundwater flow, the water conductivity properties of fissures, pressure height and groundwater level. Hydrogeochemistry, on the other hand, examines groundwater chemistry at different scales, the chemical processes relating to groundwater and the occurrence of microbes in groundwater, among other things. The studies on the surface environment, which are discussed in the following chapter, are also relevant to the final disposal site.

The site studies and the Olkiluoto Site Description produced based on them serve as initial data for the safety case analyses and safety case modellings in terms of the properties and processes of the site. The current information on the site is used as initial data when modelling past time (so-called paleo modelling) and future developments (evolution modelling) as part of the final disposal safety case.

SURFACE ENVIRONMENT STUDIES AND MODELLINGS REVEAL THE FUTURE CONDITIONS OF OLKILUOTO

Studies relating to the surface environment – biosphere studies – have an essential role in the safety case. They are used as initial data in modellings that describe the travel of radionuclides in the surface environment. For these modellings, land upheaval models, among others, are important in order to see how the surface environment at Olkiluoto will develop once the land on the coast rises due to the load caused by the previous ice age (currently approx. 6 mm/a). Furthermore, climate modellings will forecast the future climate conditions, such as



■ **Figure** 22. Olkiluoto and the disposal facility (on the top left, the site as of 2020) will be located inland after thousands of years due to land upheaval (down left, the site after approximately 4,000 years) and covered by a inland ice (on the right, the site after approximately 100,000 years).

future ice ages, and their impact on the Olkiluoto area (Figure 22).

THE RESEARCH AND MONITORING PROGRAMME VERIFIES THE SUITABILITY OF THE FINAL DISPOSAL SITE

For the purpose of tracking the long-term development of the final disposal site and the disposal facility, a research and monitoring programme, called the Olkiluoto monitoring programme, is carried out in accordance with STUK Regulation Y/4/2018 and Guide YVL D.5. The monitoring programme was started in 2003 at the same time with the construction of the final disposal site, but research tracking the properties of the final disposal site comparable with monitoring has been carried out in the area since the 1980s. The monitoring programme includes various kinds of measurement and sampling. The majority of the monitoring programme's studies are carried out underground, either in the disposal repository or research holes drilled in the area, but research is also being conducted overground and at a distance of several kilometres from the actual final disposal site. The studies in the monitoring programme are continuous in nature but their intervals vary: some of the studies are hourly measurements while others involve recurring sampling with an interval of several years.

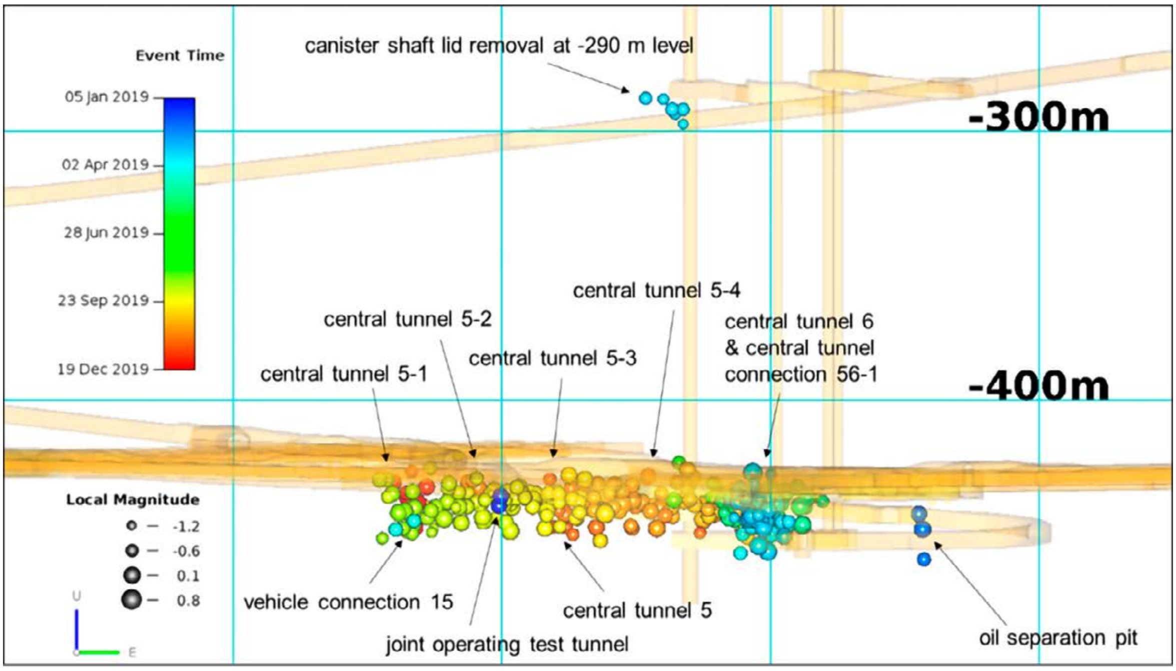
The monitoring programme is divided into five fields:

1. Rock mechanics
2. Hydrology and hydrogeology
3. Hydrogeochemistry
4. Surface environment
5. Monitoring of engineered release barriers

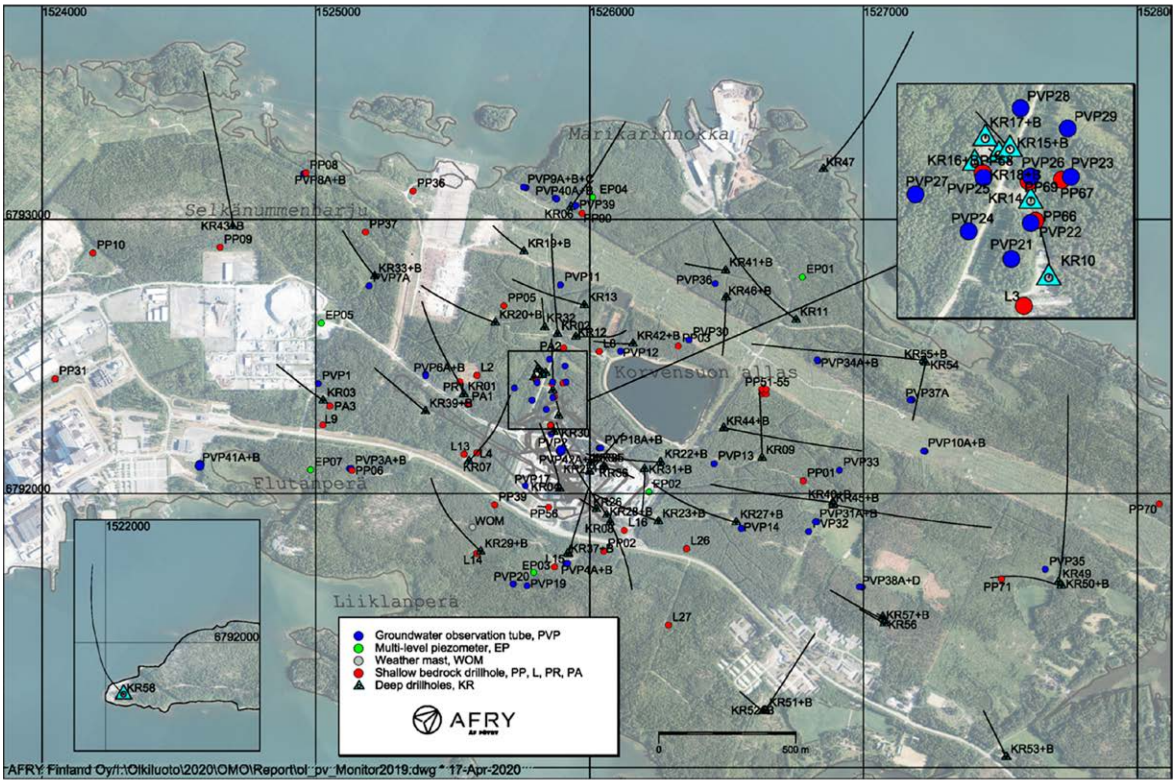
Rock mechanics monitoring tracks the microseismic events at Olkiluoto and the nearby area (Figure 1), rock block movements and land upheaval. Furthermore, bedrock temperature is measured at the disposal repository, and events detected on the tunnel rock surfaces (such as flaking of rock) are recorded.

The hydrological and hydrogeological monitoring are based on measuring groundwater levels and flow in numerous deep and shallow drilled holes and groundwater pipes in the Olkiluoto bedrock (Figure 24). In addition, the amount of water leaking into the disposal repository is measured at several observation points in ONKALO. The hydrogeochemistry monitoring is based on tracking the chemical composition of bedrock and soil groundwater. Groundwater samples are collected for chemical analyses at the same observation points where hydrological monitoring measurements are carried out.

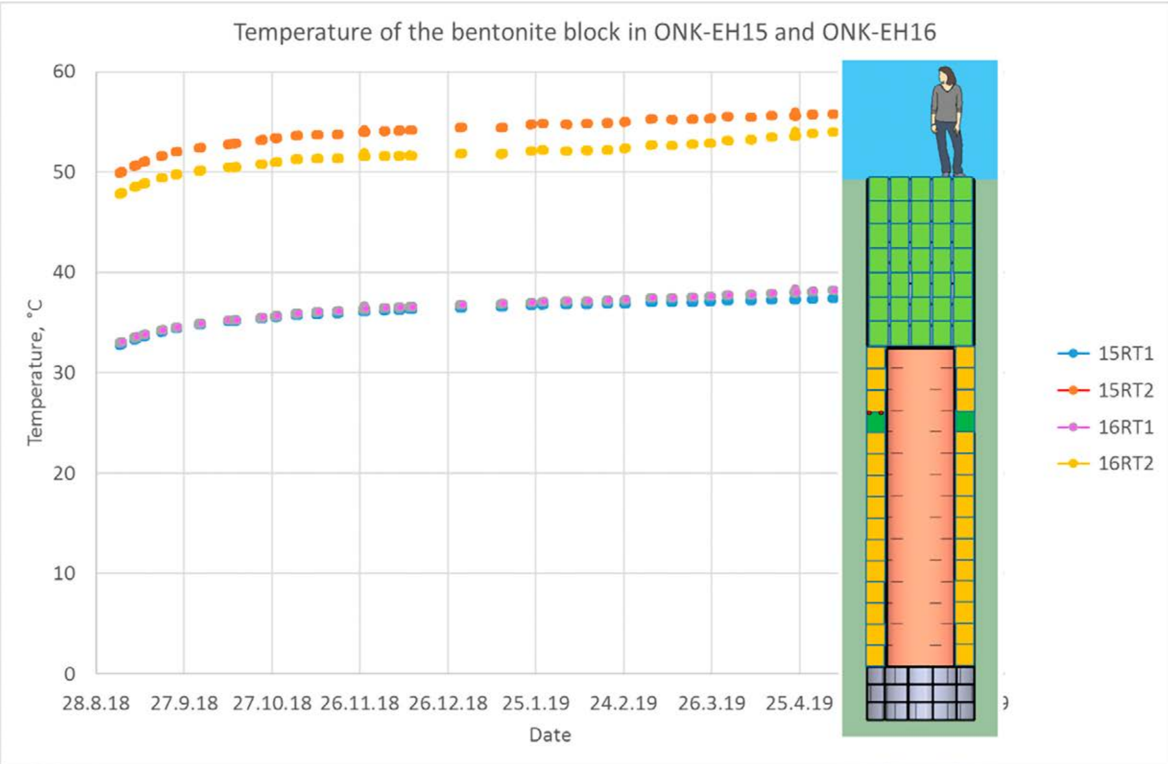
The purpose of surface environment monitoring is tracking the environmental impacts from final disposal activities. The tracking includes, among other things, environmental noise and surface



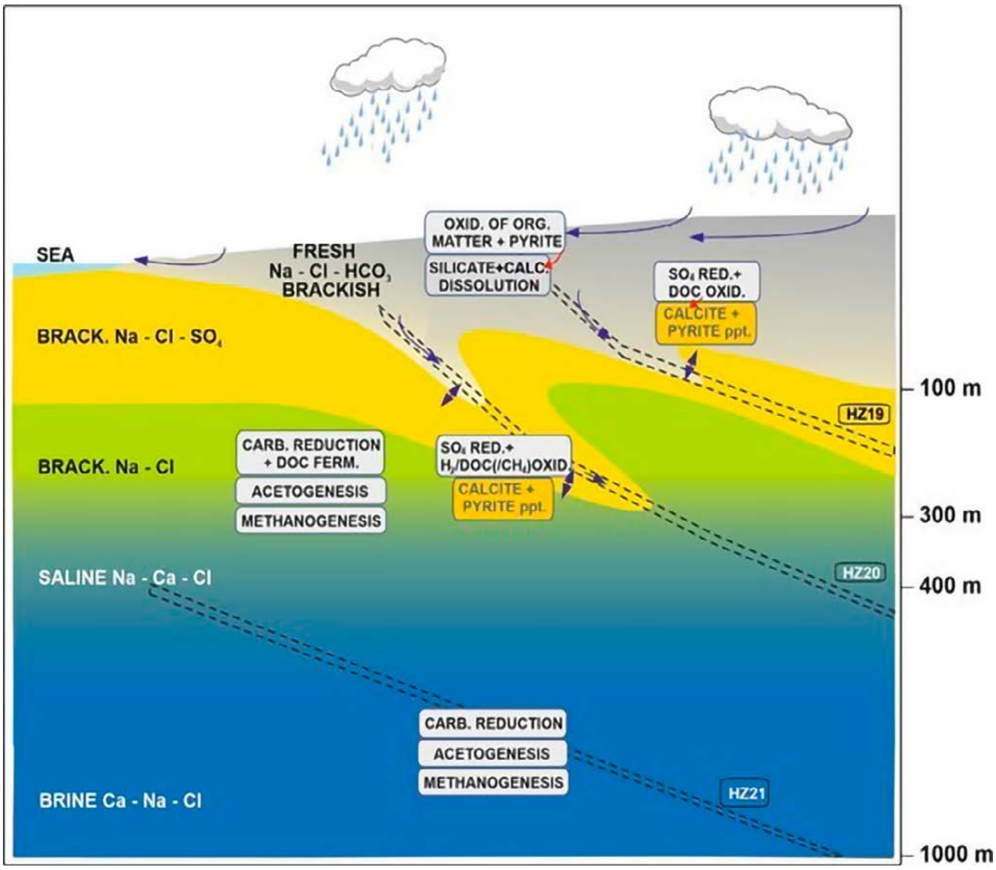
■ **Figure** 23. An example of microseismic event tracking at the disposal facility in 2019. All the seismic events in the figure are related to the blasting during the construction of the disposal facility.



■ **Figure** 24. The location of drilled holes, groundwater pipes and other research holes in the Olkiluoto area.



■ **Figure** 25. Bentonite buffer temperature measurement results during the full-scale final disposal test (FISST).



■ **Figure** 26. The hydrogeochemical basic state and the stratification of the different groundwater types at Olkiluoto.

runoff measurements and the following of the ONKALO effluent, dumping area runoff, private borewells and weather conditions.

The monitoring of engineered release barriers refers to the tracking of the performance of the engineered release barriers installed in the disposal repository (copper canister, bentonite buffer, deposition tunnel backfill and plug). The performance of the release barriers can be tracked directly by installing measuring sensors on components, indirectly via the results of other monitoring fields or through tests carried out at the disposal repository (Figure 25).

The different monitoring programme fields are strongly interconnected, and the results generated by the programme should be evaluated in terms of the overall complex. For example, construction on the ground surface may cause temporary changes in the groundwater composition or level in the surface section of soil or bedrock. Furthermore, when underground spaces are open, they also have local, temporary effects on the pressure heights of deep bedrock groundwater and, further, in the chemical composition due to the local, temporary disturbances that pressure reductions cause in the hydrogeochemical basic state. The mixing of waters, on the other hand, leads to detecting changes in the chemical composition of groundwater samples obtained from a drilled hole compared to previous results. Several memoranda and reports are created annually on the results of the monitoring programme fields in line with the YVL Guides. The published annual reports from the different fields are a summary of the individual year's research results but also of the longer-term developments observed at the final disposal site and disposal facility.

The most important aim of monitoring is tracking that the conditions in the disposal facility and the final disposal bedrock remain favourable for final disposal and meet the related requirements. Furthermore, monitoring data is also used when collecting material for the purposes of the modellings used in the assessment of long-term safety. The results obtained from the monitoring programme are provided to the constructors and designers of the disposal facility in order to take into account the impact of construction on the bedrock and the surface environment during the work. Another purpose of the monitoring programme is supervising the performance of the engineered release barriers in order to verify their expected and anticipated behaviour.

Protection zones for the final disposal area

The protection zones for the final disposal area and Olkiluoto are described in Appendix 3 to this application, "Description of settlement and other activities on the nuclear facility site and in its vicinity, including land use planning arrangements".

THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL IS SAFE

The long-term safety of the solution is paramount in the final disposal of spent nuclear fuel. It is evaluated and demonstrated with the safety case. The safety case assesses safety over the course of hundreds of thousands of years. The Radiation and Nuclear Safety Authority evaluates and approves the safety case as part of the safety assessment for the operating licence application documentation. A favourable safety assessment is a prerequisite for issuing an operating licence for the encapsulation plant and disposal facility. The safety case for long-term safety is available on Posiva's website.

According to the international definition, a safety case refers to all of the technoscientific documentation, analyses, observations, examinations, tests, and other evidence for justifying the reliability of the assessments made on the long-term safety of final disposal. At Posiva, this means demonstrating the functionality of the geological final disposal solution – which has been studied and tested for more than four decades – in the bedrock conditions at Olkiluoto and demonstrating the occurrence of radiation doses into the environment as a result of one or more engineered release barriers failing and radioactive substances being released from the disposal repository into the living environment.

The set of safety case documents demonstrates the compliance with the requirements related to long-term safety.

The first comprehensive safety case prepared exclusively for Olkiluoto was the TURVA-2012. It was preceded in 2010 by a tentative version of the safety case summary report for a spent nuclear fuel disposal facility planned at Olkiluoto (Posiva 2010). The report presented the technical final disposal plan and safety concept valid at the time as well as a summary of the formation of

Figure 27. The set of safety case documents.

scenarios used in the review of the developments of the final disposal system. The long-term safety of final disposal was also assessed in terms of compliance with regulatory requirements (Posiva 2010).

The TURVA-2012 safety case was prepared for the construction licence application for the Olkiluoto disposal facility as a report portfolio comprising main reports and background reports. The safety case synthesis report (Posiva 2012, Synthesis report) presented a summary of the design bases, safety case methodology and the key findings of the performance analysis and safety analysis for the disposal facility to be constructed at Olkiluoto. Furthermore, the report presented a summary of the justifications supporting safety, an assessment of compliance with regulatory requirements concerning long-term safety and the safety case and an assessment of the reliability of long-term safety and Posiva Oy's safety analyses. It is the opinion of Posiva Oy that the safety of final disposal was demonstrated sufficiently reliably for the construction licence application (Posiva 2012, Synthesis report). STUK approved the safety case for the construction licence application but set 34 requirements as areas for improvement in the next safety case. STUK will assess their implementation in connection with assessing the safety case for the presently submitted operating licence application. The safety case will be updated in connection with the periodic assessment carried out at least at 15-year intervals, which ensures, among other things, that the latest research data has been taken into consideration.

The safety of the final disposal of spent nuclear fuel is evaluated during and after the operational activities of the disposal facility. The review period for long-term safety is divided into different time periods from the approximately 100 years of operation to the following thousands or hundreds of thousands of years and up to a million years. Among other things, it has been analysed in the safety case how the final disposal solution will withstand earthquakes, future ice ages up to a million years and the stress caused by inland ice (Figure 28).

Even though it will never be possible to

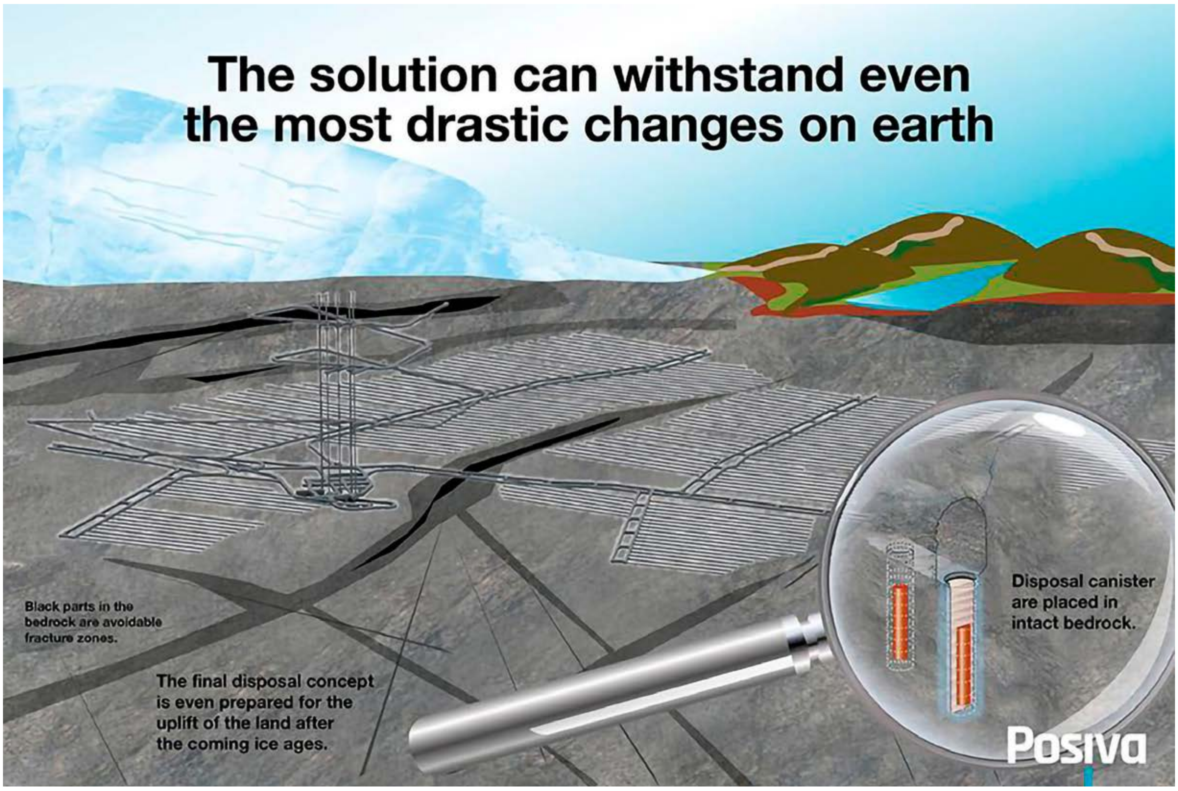


Figure 28. The ice ages have also been considered in the assessment of the long-term safety of final disposal comprehensively examine and evaluate all the possible developments, the safety case allows for demonstrating that, even based on a conservative assessment, the final disposal of spent nuclear fuel will not result in harm to people or the environment.

The reports that make up Posiva's safety case are also publicly available on Posiva's website.

THE SAFETY CASE EVALUATES LONG-TERM SAFETY WHILE COMPREHENSIVELY CONSIDERING DIFFERENT FUTURE DEVELOPMENTS

In line with the long-term safety principles, the long-term safety of final disposal is based on the multi-barrier principle applied in the final disposal of spent nuclear fuel, which comprises the engineered barrier systems (EBS) and the bedrock surrounding the disposal repository. The engineered release barriers include the final disposal canister, bentonite buffer, the deposition tunnel backfill and the facilities' closure structures. Their purpose is to act as the first protective structures against the spread of radionuclides. The primary purpose of the bedrock is to establish favourable conditions for the long-term performance of the engineered release barriers, while also contributing to the limiting or slowing down of the travel of radionuclides. According to the multi-barrier principle, final disposal is safe even if the performance of an individual release barrier is degraded.

In the safety case, the examination of the final disposal system and developments in its environment is divided into a performance assessment and an analysis of radionuclide release scenarios.

The performance assessment addresses the fulfilment or non-fulfilment of the performance targets in different development scenarios, which cover the main uncertainties related to the future development of the entire final disposal system. As its initial data, the performance assessment describes the rock and the built underground system with its associated uncertainties, the most important of which are presented as undetected quality deviations, initial-state faults, in the underground disposal facility. Uncertainty about future climate developments is covered by two alternative climates whose uncertainties are based on the RCP scenarios of the International Panel on Climate Change but extend the descriptions of climate developments over the entire review period of one million years. This includes 7–8 ice ages with their preceding permafrost and subsequent temperate climate episodes. One of the scenarios corresponds to the expected course of development, assuming that the release barriers operate as planned. The performance analysis looks at four different time periods separately:

1. Early stage of development up to 10,000 years;
2. The rest of the temperate period until the next permafrost phase;
3. The next permafrost phase and subsequent glaciation;
4. The time of repeated glacial cycles up to one million years.

The scenarios formed in the performance assessment have been divided in accordance with the Decree and the YVL Guides as follows:

- Baseline scenario: The goals set for the safety functions are met.
- Variant scenarios: More broadly, situations where the final disposal system is malfunctioning.

"What if" scenarios based on unlikely developments, in which highly unlikely events that compromise long-term safety cannot be completely ruled out. In addition to the above, the performance assessment creates a scenario in line with the expected course of development, in which the release barriers operate as planned, but which takes into account the identified potential initial-state faults.

The performance assessment confirms that when the release barriers operate as planned, i.e. as expected, any radioactive releases from the disposal facility will not only take place in the distant future, but also be well below the limits set by the radiation safety authority. However, in the context of uncertainties, it is possible that the consequences of significantly worse-than-expected conditions or unlikely events will be significantly greater. But even in this kind of case, the radioactive release limit values set by the authority are not exceeded. This supports the view of the reliability of performance assessment. In addition, some highly unlikely human-induced events have been identified that could disrupt the disposal repository.

Modelling of the release and travel of radionuclides examines the radiological effects of radionuclides that may be released from the disposal repository, as well as the uncertainties associated with these estimates. The uncertainties can be divided into three categories: (i) scenario-related uncertainties; (ii) model-related uncertainties; and (iii) parameter-related uncertainties. Uncertainties related to the scenarios have been identified and addressed as part of the performance analysis as described above. Uncertainties related to the models and parameters are handled by deterministic and probability-based analyses in accordance with the applicable YVL Guide (YVL D.5, sections A08a and A09). Observation-based analysis consists of individual calculation cases that separately consider some of the uncertainties associated with the assumptions or parameters of the model. In probability-based analysis, a large number of cases are calculated by varying the parameter values according to the selected probability distributions.

The calculation cases analyse releases in the baseline scenario and under unlikely or hypothetical developments. The baseline scenario assumes that the performance targets of the release barriers are met, in which case the release of radionuclides is only possible from the low and intermediate level waste disposal repository. The unlikely and hypothetical developments are based on scenarios identified in the performance analysis that may lead to the release of radionuclides. In addition, the release and travel of radionuclides have been analysed in several “what if”-type reviews. These cases are not directly related to the events identified by the performance analysis. Instead, they are used to test things such as the effects of the deterioration or loss of individual safety functions on the operation of the final disposal system.

The groundwater flow simulation underlying the radionuclide release and travel analyses has been repeated for ten different fissure network realisations. In the release and travel calculations, it thus is possible to distinguish the uncertainty resulting from the inherent heterogeneity of the rock from the uncertainty associated with the parameter data.

The effects of glacial cycles on groundwater flow have been taken into account in all radionuclide release and travel calculations. This is accomplished by varying the flows of the release paths by a time-dependent factor determined using a transient flow model prepared over the glacial cycle.

RADIATION EXPOSURE CAUSED BY THE FINAL DISPOSAL AFTER ITS CLOSURE

The key results of the environmental modelling (biosphere) are the projection of the evolution of the surface environment over the 10,000 years following final disposal, as well as the annual radiation doses to humans, plants and animals. In the current biosphere assessment, the individual doses per route of exposure, radionuclide and site form a dose distribution of the population that identifies the average individual dose in a family or small village community exposed to the highest radiation exposure and the average individual dose in the rest of the exposed population. Typical absorbed doses are calculated for plants and animals. The results of the baseline reference case are summarised below and presented in more detail in the safety case submitted to STUK, which is also available on Posiva’s website.

Radiation doses to humans

In the baseline case, releases only from the low and intermediate level waste repository, the screening analysis of the released radionuclides identified three radiologically relevant nuclides for which detailed modelling was performed: Mo-93, Ag-108m and Sr-90. Figure 29 shows the average individual dose in a family or small village community exposed to the greatest radiation exposure. The average individual dose to the rest of the exposed population behaves similarly over time, but is approximately two orders of magnitude lower. The individual dose representing the group with the highest radiation exposure is at most $6x10^{-12}$ mSv (approximately 1,300 years after the closure of the disposal

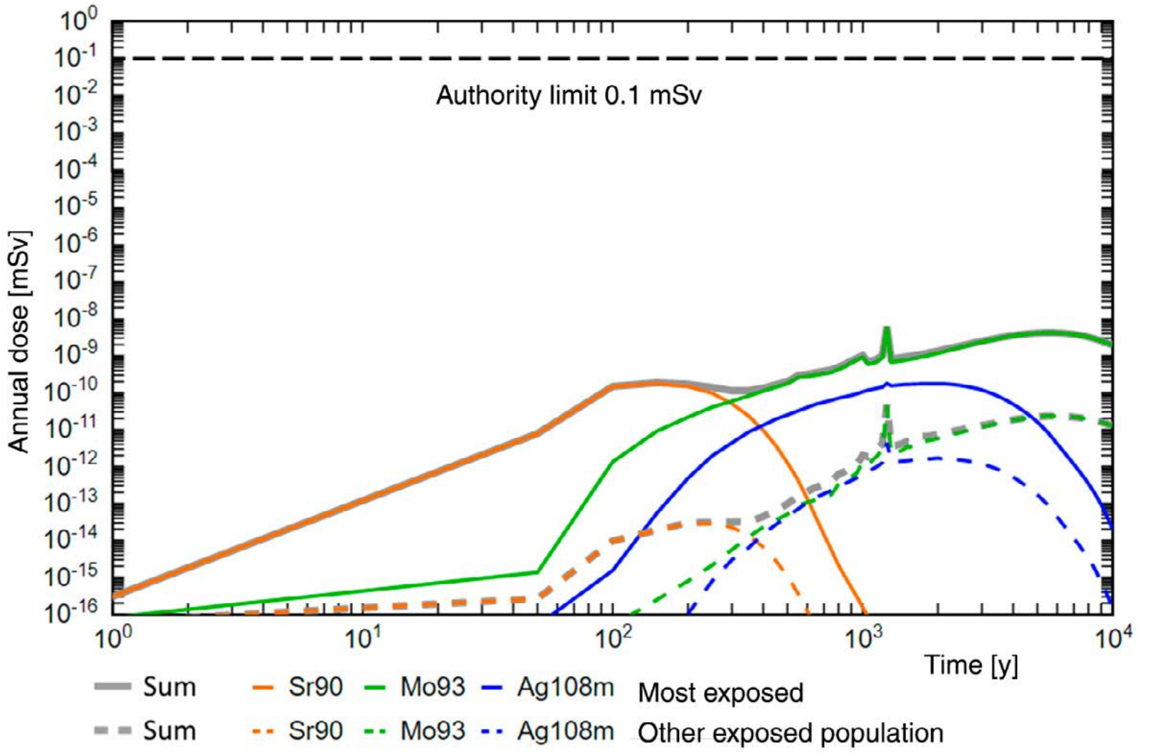


Figure 29. Average individual dose to the most exposed family or small village community and to the other exposed population, as well as the proportions of radionuclides in the baseline case after the closure of the disposal repository.

repository), and the average individual dose to the rest of the exposed population is at most 5x10^{-14} mSv (approximately 1,300 years after the closure). These results are one hundred thousandths and one millionths below the set radiation dose limits (Figure 29). In practice, the releases of Mo-93, Ag-108m and Sr-90 determine the magnitude of the radiation doses in the reference case.

All in all, the radiation doses from the possible releases are very small (under one millionth) compared to the background radiation dose to people in Finland (average effective radiation dose), which is 5.9 millisievert (mSv) annually. Most of this, some 4 mSv per year, comes from radon in indoor air, while some 1.1 mSv is received from other sources, such as X-ray examinations and airline travel.

Radiation doses to plants and animals

Typical absorbed doses are calculated for plants and animals. In the baseline scenario, the highest typical dose rate (average absorbed dose rate weighted according to the surface areas of contaminated habitats suitable for each organism) of 5.9x10-^{10} µGy/h occurs approximately 1,200 years after the closure of the disposal repository to Marenzelleria mud worms. This is several orders of magnitude (approximately one billionth) below the reference value of 10 µGy/h proposed by the international ERICA and PROTECT projects. The same is the case for the other 45 reviewed plant and animal species representing the terrestrial and aquatic ecosystems around Olkiluoto.

CONSIDERATION OF RARE EVENTS IN THE ASSESSMENT OF THE LONG-TERM SAFETY OF FINAL DISPOSAL

In addition to the baseline scenario for long-term safety, rarer events that may be significant in terms of radionuclides travelling to the ground surface are examined in connection with the operating licence application.

The developments leading to releases identified in the performance analysis affect canister integrity over several different time periods. Unusually high isostatic stress is possible during the ice age maximum. Rock movement is most likely to occur during the retreat phase of glaciation. Chemical erosion and consequent corrosion of the canisters can lead to canisters breaking at different times, but the development of conditions leading to chemical erosion first requires prolonged infiltration of dilute water into the deposition holes.

The effects of a single canister breaking due to isostatic stress have been estimated by assuming that the canister breaks at the maximum point of the first ice age, approximately 60,000 years after the closure of the repository. The model's uncertainties have been mapped extensively. The most significant nuclides in these cases are I-129, Cl-36 and Ra-226. Of these, Ra-226 is strongly retained in the bedrock and will not travel to the ground surface. Both in the reference case and in all alternative calculation cases, the standardised total release from the bedrock is less than a hundredth from the regulatory release limit set in Guide YVL D.5.

In the baseline case, rock movement is assumed to cause the failure of one canister during the withdrawal phase of the first glacial period approximately 68,000 years after the closure of the facility. The model's uncertainties have been elucidated in a calculation case where rock movement is assumed to reactivate cracks in the vicinity of the deposition hole and thus lead to an increase in groundwater flow. The effect of rock heterogeneity has been assessed by placing the breaking canister in all deposition holes intersected by a gap larger than 150 m. Release rates are dominated by the same nuclides as in the case of isostatic stress. Release from the bedrock is dominated by I-129 and Cl-36. In the case of one breaking final disposal canister, the maximum standardised release rate is approximately three orders of magnitude lower than the upper limit given in Guide YVL D.5. Based on the performance analysis, the maximum number of breaking canisters during rock movement could be 9 final disposal canisters.

A canister breaking due to corrosion is the result of an increasing stream of sulfide to the canister surface as a result of buffer moving out of place. In the baseline case, chemical erosion is assumed to start when the cation concentration in the deposition hole is diluted, as a result of dilute water seeping from the surface, to the reference level defined in the performance analysis (8 meq/l). In this case, the number of canisters that break in one million years is 14. The model's uncertainties have been taken into account by calculating cases where a more cautious cation concentration limit is used for the onset of erosion (12 meq/l), as well as a thinner copper corrosion thickness. In these cases, the numbers of breaking canisters are 38 and 111, respectively. In these disturbance cases, the highest standardised release rate from the bedrock is slightly under one tenth smaller than the regulatory upper limit set in Guide YVL D.5. The most significant nuclide in most cases is Ra-226.

"What if" cases

Calculation cases examine the deterioration of individual safety functions. The calculation cases are divided into five different groups. One group of calculation cases examines the safety functions of the low and intermediate level waste disposal repository. Four groups of calculation cases look at the disposal repository for spent fuel. These calculation cases are divided into groups by time such that, in different groups, the deterioration of safety functions will result in canister breakage within a few hundred years (canister(s) expected to break 300 years from now), a few thousand years (canister(s) expected to break from 1,000 to 10,000 years from now), a few tens of thousands of years (canister(s) expected to break 60,000 years from now) or a few hundred thousand years from now (canister(s) expected to break 300,000 years from now).

Only the breaking of a canister can lead to the release of radionuclides. Thus, the ultimate assumption of "what if" cases is that one or more canisters will break within the selected time window for one reason or another. In addition, it is possible to consider the simultaneous degradation of some other safety functions.

The cases to be considered are the particularly early breaking of the canister(s) during the current warm period, a case where, in addition to the breaking of the canister, fuel and metal parts dissolve faster than expected, or in addition to the above, the performance of the buffer is impaired or severely impaired. The breaking of several canisters at a later point in time is also considered in a separate calculation case. For the low and intermediate level disposal repository, cases are considered where the concreting of the waste deteriorates faster than expected, the chemical conditions are different than expected or the flow in the bedrock is strongly canalised. Finally, by looking at releases to the vicinity and the bedrock separately, it is possible to assess a situation where the ability of the bedrock to hinder the travel of nuclides is impaired.

In all cases, the maximum standardised release rate from the bedrock is at least one order of magnitude lower than the upper limit of Guide YVL D.5, i.e. approximately one tenth of the upper limit. On this basis, it can be stated that the radiation doses resulting from the final disposal are below the regulatory limits and are considerably lower than the normal radiation dose caused by background radiation.

The release and travel of radionuclides have also been examined in probabilistic analyses. The review has covered releases from the low and intermediate level waste disposal repository and spent fuel disposal repository in release scenarios derived from performance analysis and involving isostatic loading and rock movement. Probability-based uncertainty and sensitivity analyses have examined the effects of both epistemic and aleatory uncertainties. A simplified bedrock description has been used in all probability-based calculation cases. Sufficient accuracy of the simplified bedrock model has been ensured by separate comparison cases. In the probability-based calculation cases, the results of the analyses are also below the limit values set in Guide YVL D.5.

RELIABILITY OF THE MODELLING OF LONG-TERM SAFETY

The long-term safety is demonstrated in the safety case through various modellings. In order to demonstrate the reliability of the models, it is estimated that a comprehensive group of conceptual, mathematical and computational models represent all phenomena significant for the calculation in question sufficiently and are, thereby, appropriate.

In conceptual models, reliability indicates, for example, that the suitable phenomena, events and processes are included in the model and their interaction is considered. Where possible, the definition of conceptual models is carried out by comparing them to equivalent conceptual models used in other countries. Experimental results and natural analogies may improve confidence in all appropriate phenomena, events and processes being included in the conceptual models.

The reliability of mathematical and computational models is based on the reliability of the underlying conceptual models (see above) and on validation, which typically includes a comparison of the results of computational modelling with experimental results and/or observations from natural processes. Usually, laboratory tests are well managed, but they cover short time periods in relation to the total time scale of final disposal. On the other hand, natural processes, i.e. natural analogies, often cover sufficiently long time scales, but the environmental conditions affecting the natural processes are not as precisely known as laboratory conditions.

In computational models, reliability also refers to the verification of code; it is a process for ensuring that the equations in the mathematical model are solved correctly and with sufficient precision by using the numerical algorithms included in the code.

RELIABILITY OF THE SAFETY CASE

Posiva has accumulated very broad experience and knowledge on the creation of a safety case as well as background studies and modellings. The safety case prepared for the operating licence application is the second fully comprehensive safety case that Posiva has completed for the Olkiluoto final disposal site. STUK provided feedback on the first safety case, which was completed for the construction licence application, and this feedback has been considered in the safety case submitted in connection with the operating licence application.

During the creation of the safety case, Posiva has obtained opinions and comments from a vast group of international experts in long-term safety. Furthermore, the quality of background studies has been improved by developing centralised information management systems. The applied models and methods have been recorded and deemed suitable for the assessment. The development and creation of the safety case has been tracked in joint meetings with STUK, and STUK has had the opportunity to comment on the safety case before its completion. The safety case has been completed based on national and international recommendations and requirements.

The “Complementary considerations” report in the safety case contributes to the reliability of the safety case as, among other things, natural analogies can be used to justify the suitability of copper and clay for ensuring long-term safety.

Despite the detailed analysis of many assessment cases that have been derived carefully and methodically, the currently available information does not indicate that there are unsolved problems that could compromise safety. The safety case is part of the periodic safety assessment. According to the Nuclear Energy Act, the disposal facility must undergo periodic safety assessments at least at 15-year intervals, and long-term safety will be reassessed in connection with this assessment.

STUK assesses and approves the safety case based on the safety assessment it performs on the operating licence application documentation. An operating licence may be issued after a favourable safety assessment. STUK, like Posiva, uses international experts in the assessment of the safety case, which increases the reliability of the scope and quality of the safety case.

Posiva’s safety case is prepared such that it can be presented on Posiva’s website in a form that allows for detailed examination of individual topics.

SUMMARY OF THE IMPLEMENTATION OF LONG-TERM SAFETY

Before the safety case for the operating licence application, long-term safety has already been assessed at the decision-in-principle and construction licence stages. These assessments have not identified any matters that would prevent the implementation of final disposal. The long-term safety of final disposal is also comprehensively assessed in the full-scale SC-OLA safety case completed in 2021, which is part of the operating licence application documentation submitted to STUK in relation to the operating licence application for the encapsulation plant and disposal facility.

According to the safety case, the mechanically strong and corrosion resistant canisters will be placed in stable bedrock and surrounded by bentonite clay. It is very likely that they will contain all the radionuclides inside them for at least a million years. However, the possibility of individual canisters becoming damaged during this time cannot be entirely excluded. In such cases, radioactive substances could be slowly released into the environment. Canister leaks could be the result of an already damaged canister ending up in the disposal repository, a few canisters placed in unfavourable positions becoming damaged in strong earthquakes (that could occur during the retreat of the glacier at the end of an ice age), and glacial melt water eroding the bentonite clay from around a canister and causing the corrosion of the canister. However, even in a worst case scenario, the number of canister failures expected in the next hundreds of thousands of years is so little that the resulting releases of radioactive isotopes would only have a very low impact on people and the rest of the surrounding living nature. The safety assessments have also taken into account the uncertainties affecting the release of radioactive substances and their travel. The analysis of matters affecting safety continues in order to reduce the uncertainties.

The safety case has been prepared in accordance with regulatory requirements. It demonstrates that Posiva’s final disposal plans comply with the requirements in STUK Regulations (STUK Y/4/2018) and nuclear facility guides (YVL Guides) in terms of long-term safety. Compliance with the requirements has been demonstrated in detail in the set of safety case documents, which is also available on Posiva’s website.

The main result of the safety case is that the breaking of the copper canisters would require a severe loss of release barrier performance. Even in such an exceptional case, the canisters will remain intact at least until the following ice age, i.e. a period of nearly a hundred thousand years. However, the breaking of a canister would require the formation of a very thick glacier at Olkiluoto, which is not considered to be likely during the first 100,000 years. The radiation generated by spent nuclear fuel is quickly reduced; after 10,000 years, the dose rate near the fuel is less than one fifty thousandth of the level the fuel had one year after its removal from the reactor. After a hundred thousand years, spent nuclear fuel generates less radiation than a comparable amount of natural uranium ore. When also the theoretical "what if" scenarios are considered, the radiation doses to people and the environment will also remain lower than the limits set by the authority or the levels harmful to health. The assessment of long-term safety is performed over very long periods (of up to a million years), and the assessment takes into account various climate scenarios that include glaciation as well as warmer periods. The assessment has used conservative assumptions, i.e. assumptions of worse alternatives. Retrievability is maintained as a technically possible alternative at all the phases of final disposal and after the final closure of the facilities.

The final disposal of spent nuclear fuel has been estimated as safe for humans and the environment.

SUMMARY OF THE IMPLEMENTATION OF THE SAFETY PRINCIPLES

According to this report, the safety principles for the encapsulation plant and disposal facility have been designed and implemented such that the operational safety and long-term safety are ensured. Industrial and corporate safety and the emergency preparedness arrangements have also been arranged in line with the requirements by the authorities.

No radiation doses to people and the environment are expected during the final disposal activities. The long-term safety of the disposal facility has been ensured with comprehensive analyses, according to which no radioactive substances can rise from the bedrock in any manner that would have an impact on the radiation safety of people or the environment.

The Radiation and Nuclear Safety Authority assesses the documentation submitted to it in connection with the operating licence application and issues a safety assessment on its basis. A favourable safety assessment is a prerequisite for issuing an operating licence for the encapsulation plant and disposal facility.

06

REPORT ON MEASURES FOR LIMITING
THE ENVIRONMENTAL LOAD OF THE
NUCLEAR FACILITY

Kuva: Posiva Oy

TABLE OF CONTENTS

1 POSIVA'S ENVIRONMENTAL MANAGEMENT SYSTEM

Posiva Oy (Posiva) has in place a documented and certified activity management system that meets the requirements of the international standard SFS-EN ISO 14001 in terms of environmental aspects. One purpose of the activity management system is to ensure that the management of environmental aspects is guided and systematic. Posiva has specified the following environmental objectives for its operations:

- The aim of the operation is the implementation of safe nuclear waste management such that the environmental load is as low as possible.
- Any risks affecting the state of the environment are identified already at the operational planning phase.
- The personnel are aware of the environmental significance of their own work.

The environmental and energy aspects relating to Posiva's operations are being mapped out, and their significance is assessed regularly. For significant environmental aspects, management programmes are prepared and maintained for continuously improving the operations and reducing the harmful effects on the environment from the operations.

2 ENVIRONMENTAL IMPACT ASSESSMENT

The Environmental Impact Assessment (EIA) procedure is a systematic process for preparing for decision making. The purpose is to establish, early on during a specific project, a systematic and consistent overview of the effects that the project and its implementation alternatives will have on the environment. In the Finnish nuclear industry, there is a long tradition of comprehensive environmental analyses.

An environmental impact assessment according to the EIA Act was carried out in 1999 concerning the spent nuclear fuel encapsulation plant and disposal facility planned for Olkiluoto Island. An updated analysis of the environmental impacts of the spent nuclear fuel encapsulation plant and disposal facility, which examines the final disposal of 6,500 tU of spent nuclear fuel, is included as Appendix 10 to the operating licence application, *"Analysis of the risks related to the transport of spent nuclear fuel"*.

This appendix describes the essential environmental impacts of the spent nuclear fuel encapsulation plant and disposal facility and the design bases for preventing environmental damage and limiting the environmental load.

The environmental impacts of a nuclear facility will be evaluated throughout the service life of the facility. Environmental studies have been performed at Olkiluoto for more than 40 years. The studies were started with comprehensive analyses concerning the basic status of the environment, and after the Olkiluoto power plant was started, the effects of its operation have been tracked with extensive environmental monitoring programmes approved by the authorities, the most significant of which are the power plant's environmental radiation monitoring programme and the conventional release monitoring programme, which includes, among other things, the monitoring of loads caused by cooling water and wastewater. The impacts on the environment from the construction of the encapsulation plant and disposal facility have been tracked since the construction work began, and the effects from the plant and facility's operation will be followed throughout the final disposal operations.

Any unlikely but possible releases from the encapsulation plant into the environment would occur in a controlled manner through the collection and processing systems for gaseous and liquid radioactive material. The encapsulation plant has the facilities necessary for the interim storage of encapsulated spent nuclear fuel and the interim storage of low and intermediate-level nuclear facility waste. The encapsulation plant has a room reservation for processing systems for the processing of nuclear facility waste. Furthermore, Posiva's nuclear waste management will utilise the waste processing systems located in the Olkiluoto nuclear power plant area and the interim storages for intermediate-level waste (KAJ storage) and low-level waste (MAJ storage), and final disposal operations will utilise the operating waste repository (VLJ cave) and the disposal repository for very low-level nuclear facility waste (near-surface final disposal).

The assessment of environmental impacts has considered the combined impacts of the existing activities in the area and the activities that are planned for the area. There have been no substantial changes in the facility site environment that would have affected the results of the environmental impact assessment.

Posiva uses a certified environmental management system that meets the requirements of the international ISO 14001 standard. Furthermore, the Olkiluoto power plant and the spent nuclear fuel disposal facility are included in the industry's energy efficiency agreement, and the energy efficiency system is integrated into the environmental management system. Posiva's environmental management system takes into account the environmental and energy aspects over the entire lifespan, and it includes the principle of continuous improvement as regards the level of environmental protection and energy efficiency.

Figure 1. The properties of the final disposal site and the environmental impacts of final disposal have been assessed comprehensively, and the documentation has been submitted to the Radiation and Nuclear Safety Authority. Posiva publishes its research in report form on its website.

3 ENVIRONMENTAL IMPACTS FROM FINAL DISPOSAL OPERATIONS

3.1 IMPACTS FROM TRANSPORTS AND TRAFFIC

The traffic to Posiva's encapsulation plant and disposal facility comprises a small portion of the Olkiluoto Island traffic (some 5% of the overall traffic volume), so it has no major impact on the traffic volumes and the impacts caused by traffic.

Spent nuclear fuel is transported to the encapsulation plant and disposal facility from the Olkiluoto nuclear power plant and the Loviisa nuclear power plant. According to plans, nuclear fuel will be transported from Loviisa to Olkiluoto either by sea or road or their combination. The transports are scheduled to start in the 2040s, when the final disposal of spent nuclear fuel from the Loviisa plant units is scheduled to begin.

The number of fuel transports depends on the amount of nuclear fuel, size of the transport packaging and mode of transport. In the different mode of transport alternatives, the environmental impacts resulting from exhaust gas emissions are insignificant due to the small number of transports.

The radiation dose to the population in connection with the transports is considerably lower than the dose incurred from natural background radiation in the same period. However, transport container handlers and transport personnel may be exposed to higher levels of radiation during transports compared with exposure to background radiation.

Should a traffic accident occur during the transports of spent nuclear fuel, the effects caused by the resulting radiation dose would be minor, as the transport container can withstand various accident scenarios in accordance with national and international requirements.

3.2 IMPACTS ON LAND USE, CULTURAL HERITAGE, LANDSCAPE, BUILDINGS AND STRUCTURES

The normal operation of the encapsulation plant and disposal facility, anticipated operational occurrences or postulated accidents do not limit land use outside of the overground facility area. The possible releases as a result of an accident would be minor and limited to the area near the facility.

In connection with the permanent closure of the encapsulation plant and disposal facility, which is scheduled to take place in the 2120s according to the current plans, land use restrictions may be applied and recorded in the appropriate registers. The limitations may apply to drilling and excavation activities, for example.

The encapsulation plant and disposal facility will have minor impacts on the landscape. The area has no buildings that would have national or local cultural-historical value, significant constructed cultural environments or other such sites. No antiquity sites have been discovered in the Olkiluoto area.

3.3 IMPACTS ON SOIL, BEDROCK AND GROUNDWATER

The surface area required for the underground facility section is approximately

150 hectares for the final disposal of 6,500 tU of fuel. The total length of the underground tunnels is approximately 35 km after all of the spent nuclear fuel has been placed in final disposal. However, tunnels will be closed over the course of the final disposal operations as soon as they become full.

The total volume of quarry material corresponding to the amount of fuel to be placed in final disposal is approximately 1.7 million solid cubic metres. On average, approximately 20,000 solid cubic metres of quarry material are generated annually. The rock material brought up from the underground disposal repository is stored in a quarry material dumping area at Olkiluoto. If required, the quarry material can be crushed and used as a suitable backfill material for the disposal repository. It is not necessary to use all of the quarry material as backfill material for the underground facilities;

Figure 2. Understanding the current and future conditions of the final disposal site has required a great deal of research under various conditions.

it can also be used for other applications. One alternative is to sell the quarry material as such or in a crushed form as a filling or construction material, for example.

The decay heat from the spent nuclear fuel causes bedrock expansion, which will raise the land surface at the disposal repository only very little in relation to the natural land upheaval at Olkiluoto caused by the ice age. The land upheaval due to thermal expansion will amount to a few centimetres over the course of one thousand years after the final disposal.

Groundwater leaks into open tunnels from where it is pumped to the ground surface. This reduces groundwater pressure height around the tunnel system and may possibly cause the groundwater level to decrease in the Olkiluoto Island area. The volume of leaking water and the extent of its impact are reduced by sealing the rock around the tunnels as work progresses.

The impact of the excavation and construction of the ONKALO disposal repository on the groundwater level has been assessed by using computational fluid dynamics. The fluid dynamics model is continuously being updated, comparing the results to observed values. Both the modelling and the observed results indicate that the construction of ONKALO has only caused very minor permanent changes in groundwater level.

No changes directly resulting from the construction of ONKALO were observed in low groundwater before 2010; at this time, a localised increase in sulphate concentration was discovered in low groundwater results due to the construction work relating to land use above and around the ONKALO area.

Dilution of salinity has been observed in the chemical composition of groundwater in the significant water-bearing hydrogeological structure in the site scale (HZ20, HZ=hydrogeological zone) (Figure 3) and the rock surface section. The hydraulic gradient of open underground facilities caused by the construction of ONKALO has led to increased groundwater flow and the mixing of various groundwater types, which has been observed in processes in groundwater chemistry, including the formation of sulphide. The changes observed deep in the bedrock have been minor.

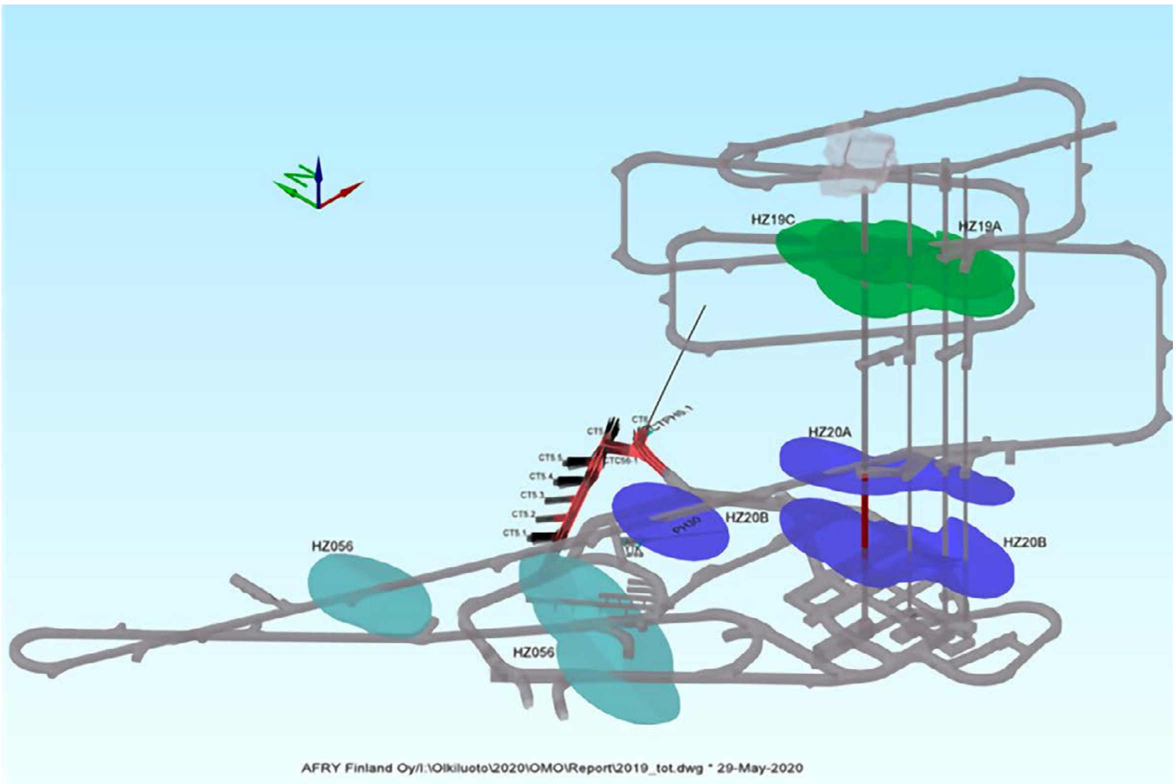


Figure 3. The most significant water-bearing hydrogeological structures in the site scale presented as discs intersecting with the ONKALO® tunnels. The structure colour codes are green: HZ19, dark blue: HZ20 and light blue: HZ056.

3.4 IMPACTS ON AIR QUALITY

Construction work, work site traffic and separate functions (e.g. rock crushing and quarry material dumping) cause local dusting. Vehicles and machinery generate emissions into the air. These emissions are minor in quantity, and they do not impact air quality outside the area.

3.5 NOISE AND VIBRATION IMPACTS

Earthworks, blasting, quarry material processing, crushing and the use of vehicles and machinery generate noise and vibration. The functions that generate vibration and noise are implemented such that they do not cause significant impacts on the environment.

The disposal repository for spent nuclear fuel is constructed as spent nuclear fuel is placed in final disposal. The noise from the excavation of the disposal repository is not heard outside the facility area. During construction, the crushing of the quarry material generates noise in the daytime. The area affected by the noise from crushing does not have anything that would be disturbed by the noise. The impacts are not significant due to the short duration of the functions and the small size of the affected area. The crushing of the quarry material will end once all the spent nuclear fuel has been placed in final disposal in the Olkiluoto bedrock.

3.6 IMPACTS ON FLORA, FAUNA AND CONSERVATION AREAS

The project's impacts on the flora and fauna are primarily related to the land areas required for buildings and structures and the related construction work. There are no significant impacts during the operation and after the closure of the disposal repository.

Most of the plants take their water from the soil water above the rock surface. Therefore, any reduction of the rock groundwater level caused by the underground facilities will not impact the flora. No significant water level reduction is expected in soil layers.

The impact from final disposal on the Liiklankari Natura area have been studied and assessed in connection with the Olkiluoto partial master planning. The Natura assessment has found that the projects made possible at Olkiluoto through general planning (including the encapsulation plant and disposal facility) do not significantly affect the nature values for which the natural conservation area, located on the south coast of Olkiluoto Island, has been included in the Natura 2000 conservation programme.

Outside the area reserved for the operation of the disposal facility, the utilisation of natural resources, such as picking mushrooms or berries, hunting, fishing and forestry, can be continued as usual.

4 IMPACT ON PEOPLE AND ATTITUDES TOWARDS THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL

4.1 SOCIAL IMPACT, IMPACTS ON THE COMMUNITY STRUCTURE, REGIONAL ECONOMY AND IMAGE OF EURAJOKI MUNICIPALITY

Section 6.10 of Appendix 10 to this operating licence application, *"An updated analysis of the environmental impacts of the plant complex"*, describes the impact on people from the final disposal of spent nuclear fuel and the attitudes of people towards the final disposal.

4.2 IMPACTS OF OPERATIONAL OCCURRENCES AND ACCIDENTS

In the encapsulation of spent nuclear fuel, the releases of radioactive substances from the encapsulation plant and disposal facility are negligible under normal conditions. The amounts of radioactive substances processed at the encapsulation plant at a time are small compared to the corresponding amounts at nuclear power plants. Due to this reason, among others, it is not possible for a severe accident to occur at the encapsulation plant and disposal facility. The general radiation safety requirements for the encapsulation plant and disposal facility are presented in the Nuclear Energy Decree, which specifies that the effective dose incurred by the most exposed individual in the population must not exceed 0.01 mSv per year during normal operation. Analyses concerning the encapsulation plant and disposal facility have demonstrated that, in normal operation, the annual radiation doses incurred by the surrounding population remain negligibly low; the radiation dose incurred by a representative person comprises approximately 0.001% of the annual dose limit for normal operations.

Operational occurrences differ from accidents such that the consequences from operational occurrences are not as severe as in accidents but operational occurrences can occur more often. In case of an operational occurrence, radioactivity may be released into individual facilities at the encapsulation plant, from where the release is filtered and conveyed outside via the ventilation system. In the disposal repository, operational occurrences and accidents that involve a release of radioactive substances are highly unlikely. In operational occurrences, the doses are, similarly, negligible; the radiation dose incurred by a representative person comprises approximately 0.002% of the annual dose limit of 0.1 mSv.

The structures of the encapsulation plant and disposal facility shall be implemented such that even potential accidents at the different stages of handling the nuclear fuel that lead to the significant damaging of the nuclear fuel will not pose an immediate health hazard to the personnel or the residents of the surrounding areas. In case of accidents, the annual doses will remain clearly below the required limit values of 1, 5 and 20 mSv per year. In an examined accident in which a transport container would fall during lifting, lose its integrity and the fuel elements in the container would fail, the release through filtering would, over the course of a year, cause a dose of no more than 0.01 mSv to a representative person. Assuming that some of the release would happen without filtering as a result of a loss of power, the dose incurred by a representative person would be 2.3 mSv, amounting to approximately half of the annual dose limit of 5 mSv.

The highest dose will be incurred immediately adjacent to the facility area assuming that this location is used for permanent residence and agriculture and home-grown products are the primary source of nutrition. Most of the dose comes via food chains from radionuclides that settle on the ground, similarly as in connection with operational occurrences.

The significance of the external radiation dose from fallout increases as the observation period lengthens. External exposure accounts for the majority of the dose accumulated over 50 years. Annual dose levels remain so low that there is no risk of immediate health effects. Similarly, based on population doses, the risk of stochastic effects remains very low.

The design of the encapsulation plant and disposal facility must take into account the impacts resulting from natural phenomena and other events external to the plant that are considered to be possible. Natural phenomena to be considered include lightning strikes, earthquakes and floods. Other events external to the plant to be considered include electromagnetic disturbances, airplane crash, wildfire and explosion. These natural phenomena and external events shall be considered in the design of the encapsulation plant and disposal facility to the sufficient extent.

5 ACTIONS TAKEN IN ORDER TO REDUCE ENVIRONMENTAL IMPACTS

During the design and environmental impact assessment work on the encapsulation plant and disposal facility, the possibilities of preventing, limiting or mitigating the adverse effects of the project by means of design or implementation have been explored.

5.1 DESIGN BASES OF RADIATION PROTECTION

During any period reviewed, final disposal must not give rise to health or environmental effects in excess of the maximum levels considered acceptable at the time of implementing final disposal. The objective of radiation protection is to ensure under all operating conditions that the principles of justification and limitation and the ALARA principle are met. Unnecessary radiation exposure shall be avoided, individual dose limits shall not be exceeded and all radiation doses shall be kept as low as reasonably achievable.

The encapsulation plant and disposal facility are designed in such a way that the radiation effects resulting from the developments considered probable do not exceed the limit values indicated above.

5.2 LIMITING THE RELEASE OF RADIOACTIVE SUBSTANCES

The operation of the encapsulation plant and disposal facility, as well as its structures and systems, are designed in such a way that the release of radioactive substances into the facility and the environment is prevented or limited by all practical means. Radiation measurements provide up-to-date information on the radiation situation of rooms. The facility has systems in place to recover radioactive materials released into treatment facilities; clean the surfaces of radioactive materials released to them; and properly treat and pack the accumulated radioactive waste.

The premises of the facility in which significant quantities of radioactive substances may be released into the air are equipped with ventilation and filtration systems designed to:

- reduce the concentration of radioactive substances in these facilities;
- prevent the spread of radioactive materials into other premises of the facility;
- prevent the release of radioactive material into the environment.

These ventilation and filtration systems also operate at their designed capacity in the event of an anticipated operational occurrence or a postulated accident.

Access to contaminated premises is limited and the spread of radioactive substances is prevented by means of protective equipment and shoe boundaries. The rooms in the radiation controlled areas are classified based on external dose rate, contamination and airborne contamination. These classifications are used in order to limit access to the rooms and, thereby, prevent the spread of radioactive substances in the facility's premises. The surfaces of the facility's premises are measured regularly in order to ensure that radioactive substances cannot spread at the facility. When leaving the radiation controlled area, employees' clothes and all equipment, including tools, are measured and cleaned, if necessary, in order to ensure that no radioactive substances are taken outside the facility's premises.

The radioactivity of the exhaust air in the radiation controlled area of the encapsulation plant is measured continuously. If radioactivity is detected in the air, the exhaust air filtration is activated and the source of the radiation leak is identified. If necessary based on the radiation measurements, the exhaust ventilation is stopped and the source of the radiation leak is identified. In rooms in which fuel elements are processed, the exhaust air is continuously being filtered for radioactive substances. The exhaust air from the canister storage space of the disposal facility is discharged through the ventilation of the canister shaft and radiation controlled area of the encapsulation plant.

At the encapsulation plant, the cleanliness of effluent is ensured with radiation measurements before it is discharged from the plant. If radioactivity is detected, the water flow in the pipes is stopped and the source of radioactivity in the effluent is identified. There is no need to separate the runoff coming from the disposal repository and the runoff coming from the non-controlled area, as it is highly certain that there is no contamination in the runoff.

5.3 LIMITATION OF EMPLOYEES' RADIATION EXPOSURE

Work spaces and passageways in regular use at the encapsulation plant and disposal facility have been located so that the dose rate of external radiation and the possibility of internal radiation exposure are minimised. Structures, systems and equipment containing radioactive substances are located in dedicated rooms or protected effectively. When these structures are opened, additional equipment will be used, if necessary, in order to prevent the spread of radioactive substances and internal radiation doses. Physical radiation protection for shielding against direct radiation is designed with sufficient safety margins. Furthermore, functions involving a considerable radiation dose rate are remote controlled.

The spaces of the encapsulation plant and disposal facility have been classified based on the estimated radiation conditions. Access to premises that require monitoring for radiation protection purposes is restricted, and the premises are appropriately monitored. The arrangements for the radiation controlled areas of underground facilities take into account the specific characteristics of these facilities and the work to be carried out there. For the operation, inspection and maintenance of the equipment, the conditions and circumstances shall be designed in such a way that the number of work steps to be carried out under radiation is as small and their duration as short as reasonably achievable.

Radiation monitoring uses personal measuring devices equipped with alarms, dosimeters, so that no one is exposed to significant radiation doses during the operation of the encapsulation plant and disposal facility. Dosimeters are used for tracking personal and work task-specific radiation doses, and the data is used for improving the effectiveness of radiation monitoring. Access to locations with particularly high radiation is prevented unless approved by radiation monitoring, and radiating items are equipped with markings indicating a radiation hazard.

5.4 RADIATION MONITORING

The purpose of radiation monitoring is to prevent humans, animals and the environment from receiving significant radiation doses by monitoring radiation and activity levels. Radiation monitoring is carried out at the encapsulation plant and disposal facility during all work in the radiation controlled area.

At the disposal facility, most of the radiation doses occur due to direct radiation from the final disposal canisters. Furthermore, there is radon in the cave facilities, the concentrations of which are kept low with ventilation. At the encapsulation plant, radioactivity may primarily be released during the unloading of the transport container and the encapsulation of fuel elements as well as the service and maintenance of systems that contain radioactive materials. All work under radiation at the encapsulation plant and disposal facility are planned in advance such that the radiation dose incurred by the persons completing the work is minimised.

At the encapsulation plant, radiation doses may occur due to direct radiation from the final disposal canister, fuel elements and other systems containing radioactive substances. At the disposal facility, the only source of direct radiation is the final disposal canister. The final disposal canister transfer route establishes an area in which unnecessary access is prevented. Access by the persons working in the area is recorded, and the radiation doses received are reliably measured. In practice, such an area is separated into its own closed area: a radiation controlled area which is accessed through a control point. The radiation doses received by staff and visitors are recorded at a checkpoint.

5.5 PREVENTION OF OPERATIONAL OCCURRENCES AND

ACCIDENTS; CONSEQUENCE MANAGEMENT

Preparations have been made for operational occurrences and accidents in the operation of the encapsulation plant and disposal facility, and particularly for their prevention. Compliance with the safety regulations for anticipated operational occurrences and postulated accidents is demonstrated by analyses in connection with the operating licence application.

In the processing and storage of spent nuclear fuel, sufficient cooling of the fuel shall be ensured and any damage to the fuel and the occurrence of a self-sustaining chain reaction of fissions shall be prevented. The spent nuclear fuel to be placed in final disposal has already cooled for several decades, and its heat generation has reduced to approximately one thousandth. The decay heat generated at the encapsulation plant is transferred from the spent nuclear fuel to the surrounding processing facilities, from where the heat is removed through passive conduction and active extraction with the ventilation systems. From a canister placed in final disposal, decay heat is transferred into the bedrock.

Control of radioactive substances at the encapsulation plant and disposal facility includes ensuring the integrity of fuel cladding, preventing and limiting the spread of radioactive releases and limiting the radiation dose incurred by the population and personnel. Furthermore, radioactivity and dose rate measurements are used for monitoring the facility's premises and possible releases into the environment. Control of radioactive substances also involves the careful processing of radioactive substances accumulated from decontamination, radioactive wastewater and solid low and intermediate-level waste.

Reactivity management at the encapsulation plant and disposal facility has been addressed in the design of systems containing nuclear fuel and systems used for processing and transfers primarily through structural solutions. The materials and geometry of fuel racks have been selected such that a critical configuration cannot be created. Furthermore, the encapsulation plant prevents water from entering the space between fuel elements by structural means and by limiting the amount of flooding water that can enter the handling cell. Canisters that have been placed in final disposal will maintain their subcriticality also over a very long period in expected situations.

Accident analyses as well as the instructions and plans related to their prevention will be submitted to the Radiation and Nuclear Safety Authority (STUK) for approval. STUK will evaluate them as part of its safety assessment before an operating licence can be granted.

5.6 PREVENTION OF FIRE AND EXPLOSION HAZARDS

The encapsulation plant and disposal facility has been designed so that the probability of a fire is low and the consequences of the fire for safety are minor. Explosions that could jeopardise the integrity of fuel elements, canisters, equipment or facilities containing radioactive materials are also reliably prevented.

The objectives of the fire safety arrangements at the encapsulation plant and disposal facility are:

- to prevent fires;
- to detect and extinguish fires quickly;
- to prevent the spread of fires to premises where they could jeopardise the safety of the handling or storage of spent nuclear fuel;
- to minimise explosion hazards.

In the encapsulation plant and disposal facility, fire and explosion prevention is primarily based on space design and fire compartmentation. The materials used are generally non-combustible and heat resistant. Materials or equipment which increase the fire load or present a risk of ignition and explosion shall not be unnecessarily placed in or in the immediate vicinity of fire compartments critical for safety. Premises with significant fire load concentrations are separated into their own fire compartments.

The encapsulation plant and disposal facility is equipped with an automatic fire alarm system designed to locate the fire with sufficient accuracy. In addition, the facility premises will be equipped, if necessary, with an extinguishing system suitable for the site and first-aid firefighting equipment suitable for operational fire protection. The fire alarm and extinguishing systems will also work effectively in the event of anticipated operational occurrences and postulated accidents.

The explosives used in rock construction are stored above ground in their own protected storage facilities. No more explosives than permitted shall be transported at one time, and the explosives storages shall be located in such a way that a possible explosion does not endanger the safety of the disposal facility. Explosives are transported from the ground surface to the disposal repository by a different route or at a different time than radioactive materials. In rock construction, a kind of explosive is also used whose ingredients are safe by themselves and are only mixed into an explosive combination at the blasting site. In excavation work, a sufficient safety distance is always left between the blasting site and the deposition tunnels containing final disposal canisters.

5.7 TAKING EXTERNAL EVENTS INTO ACCOUNT IN DESIGN

The design of the encapsulation plant and disposal facility has taken into account the impacts resulting from natural phenomena and other events external to the plant that are considered to be possible. When preparing for external threats, it is essential to ensure that no sudden imaginable phenomenon can lead to the impairment of strength of structures important for the safety of the encapsulation plant. In this respect, the most relevant phenomena are severe storm winds, earthquakes, aircraft collision and possible explosions in the facility area. Sufficient protection against the effects of severe rain or snowfall and lightning strikes shall also be arranged. Furthermore, it shall be ensured that extreme temperatures will pose no significant danger to the safety of the facility. This preparation shall ensure that various external threats will not result in a significant threat to nuclear safety or the containment of radioactivity and, instead, the possible effects will affect the operability of the facility, at most.

Figure 4. The encapsulation plant is built to withstand various external events. Industrial, fire, radiation and nuclear safety have been considered in the implementation of the plant and facility.

The disposal facility located deep underground is better protected against various external threats compared to the encapsulation plant. Thus, it is highly unlikely that any external threat could directly impact the nuclear safety of the disposal facility. However, threats may have indirect impacts. Many support functions important for the operation of the disposal facility, such as electricity distribution, ventilation, cooling, heating and pumping of leakage water are, at least partly, based on equipment and structures located in overground buildings in the facility area. However, the above support functions are not necessary in terms of nuclear safety, as fuel integrity would not be compromised even if all the equipment became inoperable. This is due to the facility's good passive safety properties. The loss of the support functions could interrupt the facility's normal operation and lead to the disposal facility becoming flooded to some extent as a result of the water extraction pumping stopping. Overall, it can be stated that sufficient protection of the overground facilities is important for personnel safety, the facility's availability and preventing financial damage.

6 MANAGING THE IMPACT OF SPENT NUCLEAR FUEL TRANSPORTS

The transportation of spent nuclear fuel during the operation of the encapsulation plant and disposal facility is subject to a separate licence, and the necessary licences for the transportation of nuclear materials and nuclear waste in Finland are issued by STUK. The transport cannot be commenced until STUK has ascertained that the transport equipment and transport arrangements and the arrangements for physical protection and emergency planning meet the requirements set for them and provision has been made for indemnification regarding liability in case of nuclear damage. *(Nuclear Energy Decree, Sections 56 and 115)* The transports of spent nuclear fuel from Loviisa are scheduled to begin in the 2040s. Spent nuclear fuel transports from the interim storage of the Olkiluoto nuclear power plant will take place as internal transfers within the plant area.

High requirements have been set for the transport packaging, its handling, preparedness for accidents, and documentation. The transport packaging must not lose its radiation protection properties even in the worst conceivable accident. During transportation, the spent nuclear fuel inside the transport packaging must remain subcritical under all conditions. The transport packaging is subject to stricter requirements than usual in exceptional situations.

The purpose of the provisions on the transportation of radioactive materials is to ensure the safety of transportation in such a way that the transport packaging used in each case adequately protects the environment and the substances carried, so that the environment is not exposed to loads higher than the permitted radiation dose. The provisions on a so-called type B(U) container based on the International Atomic Energy Agency's guidelines for the safe transport of radioactive material (IAEA 2018 edition *"Regulations for the safe transport of radioactive material"*, SSR-6) apply to the transport packaging of spent nuclear fuel. The type of packaging used for transport must withstand tests to ensure the suitability of the container type for the transport of spent nuclear fuel. One or more transport containers that comply with the requirements will be obtained for spent nuclear fuel transports from Loviisa. For internal transfers at Olkiluoto, the fuel from OL1 and OL2 will be transferred in a container currently used by TVO which is licenced as a B(U) type container. A transfer cask for OL3 fuel will be obtained later as the final disposal of OL3 fuel becomes relevant.

For transports, it is required that the radiation dose rate at a distance of one metre from the outer surface of the packaging must not exceed 0.1 mSv/hour, and at the surface 2 mSv/hour. In addition, the packaging and the nuclear fuel transported inside it must be able to withstand the fatigue load caused by the vibrations normally generated during transport. The temperature of the transport environment is also important for the probability of damage to the materials. During transportation, the ambient temperature must not be too low. In transports, only a very small leakage flow into the environment is allowed from the packaging. According to the IAEA's requirements, the transport packaging must be able to withstand, during routine conditions of transport:

- a water spray for one hour;
- a drop from a height of 0.3 to 1.2 metres onto an immovable surface;
- a compressive load equivalent to 5 times the weight of the packaging;
- a penetration test where a 6 kg steel bar is dropped from a height of one metre towards the side wall of the packaging.

The radioactivity of the surface contamination of the packaging (radioactive substances possibly on the surface of the packaging) may not exceed 4 Bq/cm2 and, for alpha decay radionuclides, 0.4 Bq/cm2. In exceptional scenarios, the spent nuclear fuel transport packaging must meet significantly more stringent requirements. Among other things, it must withstand:

- a drop onto an immovable surface at the most unfavourable angle of impact from a height of nine metres;

- a drop onto a steel bar 0.15 m in diameter from a height of one metre;
- exposure for at least 30 minutes to a fire with a flame temperature of at least 800 °C;
- immersion at a depth of 200 m for at least one hour.

The tests that are related to exceptional scenarios strive to cover the mechanical and thermal loads caused by potential accident situations, including impacts to the packaging caused by collisions and a fire in a vehicle transporting flammable liquids. In addition, it must be kept in mind that, in reality, the object is not immovable. In the nine-metre drop test, the transport packaging reaches a speed of almost 50 km/h at the moment of impact, which is also a possible collision speed with another vehicle or obstacle, even in practical accident situations. During transportation, the spent nuclear fuel inside the transport packaging must remain subcritical under all conditions.

Road transports are supervised and accompanied by the necessary escort personnel: drivers of warning vehicles, drivers of police vehicles and other necessary persons, such as a radiation protection technician. During passage through larger urban areas, several police patrols are needed for traffic control. When transporting spent nuclear fuel, the escort is also accompanied by security personnel. Transport speed limits are low, and large urban areas are to be avoided. Similarly, the other modes of transport will be supervised.

7 MANAGEMENT OF IMPACTS FROM EXCAVATION AND CRUSHING

The nuisance caused by noise and other disturbance during excavation and crushing in the vicinity of the encapsulation plant and disposal facility can be mitigated by scheduling the work steps for daytime. The quarry pile is used in crushing as noise protection. The crushing plant and quarry pile can be located so that there are no buildings left in the noise and dust areas.

The Olkiluoto seismic system has been used to measure the effects on the bedrock from the construction sites for the disposal facility and the encapsulation plant. The status of Olkiluoto is constantly monitored through measuring devices, and through the system it is possible to monitor in real time what has happened at the construction sites. The blasting at the site of the disposal facility has had a maximum magnitude of around ML=1.4. The excavation work for the encapsulation plant has had a maximum magnitude of around ML=1.5. At both construction sites, more than 99% of the blasts fall below magnitude ML=1.0, and 90% fall below ML=0.5.

The most significant findings have been excavation-induced micro-earthquakes in 2017 and 2018 at the disposal facility. The magnitude of the micro-earthquakes has been ML=-0.5 at most. Compared to the excavation blasts, the micro-earthquakes release around 1,000 times less energy. The results are reported regularly, and the information is submitted to the Radiation and Nuclear Safety Authority.

7.1 CONSTRUCTION OF SURFACE CONNECTIONS

The location of the opening of the driving tunnel and the upper end of the shafts has been chosen so that they are above the surface of the Korvensuo water basin and also sufficiently above sea level so that water will not flood the driving tunnel or shafts as a result of external disturbance. The location of the entrance has also taken into account existing power lines, transformer stations, water basins, pipelines, roads and the location of the potential final disposal area in the bedrock, so that the opening is optimally located in relation to them as well. In the bedrock, the driving tunnel is located in such a way that the zones of rock fracture are penetrated as little as possible and the studies necessary to characterise the desired rock areas can be carried out.

8 MANAGEMENT OF IMPACTS FROM THE ENCAPSULATION PLANT

The encapsulation plant has been designed in accordance with safety regulations so that the release of radioactive substances into the environment remains insignificant even in the event of operational occurrences or accidents. All work steps in the encapsulation plant are carried out safely without significant releases or radiation doses to personnel.

The plant complies with the national and international requirements for nuclear safeguards. Nuclear safeguards will be carried out through nuclear material bookkeeping as well as visual and technical surveillance at all stages of the encapsulation process of nuclear fuel.

8.1 CANISTER TRANSFERS FROM THE ENCAPSULATION PLANT TO THE UNDERGROUND DISPOSAL REPOSITORY

The transfer of the canisters from the ground surface to the final disposal depth takes place with a canister lift. High-level transportation safety is ensured by means of design and simple but reliable structural solutions. Furthermore, reliability, availability and safety are ensured by the maintenance and periodic tests required for nuclear facilities and by preparing for imaginable accident scenarios.

8.2 UNDERGROUND DISPOSAL REPOSITORY AND SAFETY DISTANCES FOR DEPOSITION TUNNELS

When constructing and closing the disposal repository, the aim is to preserve the original properties of the rock and to limit changes to the smallest possible area around tunnels and shafts. For example, rock is excavated using methods that keep the disturbance zone caused by excavation as small as possible. In order to determine the extent of the disturbance zone, a method has been developed at Posiva that can be used to monitor the actual quality of excavation. Water leaks are limited by avoiding water-conducting structures and by sealing leak points, for example by injection.

During the operating phase of the final disposal, when excavating the central and deposition tunnels, a sufficient safety distance is left between the excavation site and the deposition tunnels for work technical and general safety reasons. This way, the pressure wave from blasting discharged from the deposition tunnel to be excavated does not damage, for example, the wall between the radiation controlled area and the non-controlled area in the central tunnel.

8.3 CRITERIA FOR ASSESSING THE SUITABILITY OF THE FINAL DISPOSAL SITE

In Finland, the requirements for the characteristics of a final disposal site are recorded in the Radiation and Nuclear Safety Authority Regulation (STUK Y/4/2018). Here, “final disposal site” refers to a volume of rock that contains an underground disposal facility, and the requirements, as such, do not apply to the overground elements relating to the final disposal operations, such as the encapsulation plant. The premise of the safety regulations is that the bedrock properties of the final disposal site as a whole must be favourable for the isolation from the living environment of the substances to be placed in final disposal. A site with something that is obviously unfavourable for long-term safety should not be chosen as the final disposal site.

Factors that suggest unsuitability of a site include the proximity of exploitable natural resources, exceptionally high tension inside the rock, exceptional seismic or tectonic activity and exceptional values of important groundwater characteristics. No such properties have been observed in the area reserved as the disposal facility area.

The positioning of the spent nuclear fuel disposal repository, comprising the deposition tunnels and holes, is based on the rock classification made with the help of site and safety studies and its suitability criteria. Among other things, the suitability criteria take into account rock fracture, water conductivity and groundwater composition. Research on the criteria will be carried out continuously as the disposal repository is expanded over the course of the operation. The effect of the canisters' decay heat power can be controlled by means of positioning by considering the heat transfer capacity of the canisters' surroundings in the disposal repository and placing the canisters and the deposition tunnels sufficiently far apart.

The construction of the different parts of the disposal repository will be carried out in stages, so that studies on the suitability of the rock block planned for excavation and the classification of the rock will be carried out before the construction of that stage begins. The structure and properties of the rock surrounding the disposal repository that may be relevant to groundwater flow, rock movements or other issues important for long-term safety are identified and classified. Provision is made for the location of underground facilities to be moved if the quality of the rock surrounding the planned facilities proves to be significantly less favourable than the design basis.

Each final disposal canister that contains spent nuclear fuel can be transferred into a deposition hole after STUK has ascertained that the rock properties surrounding that location are acceptable.

8.4 LONG-TERM SAFETY

The mechanically strong and corrosion resistant final disposal canisters will be placed in stable bedrock at a depth of 400–450 metres and surrounded by bentonite clay. It is very likely that they will contain all the radioactive materials inside them for at least a million years. However, the possibility of individual canisters becoming damaged during this time cannot be entirely excluded. In such cases, radioactive substances could be slowly released into the environment. Canister leaks could be the result of an already damaged canister ending up in the disposal repository, a few canisters placed in unfavourable positions becoming damaged in strong earthquakes that could occur at ice retraction phases during an ice age, and glacial melt water eroding the bentonite clay from around a canister and causing the corrosion of the canister.

However, even in a worst case scenario, only a few canister failures are expected in the next hundreds of thousands of years. The resulting releases of radioactive isotopes would only have a very low impact on people and the rest of the surrounding living nature. The safety assessments have also taken into account the uncertainties affecting the release of radioactive substances and their travel. The feasibility as well as sufficient quality and safety of technical solutions will be demonstrated by tests.

The meeting of the requirements is examined in the safety case prepared for the licence application. It finds that the annual radiation doses resulting from developments that are considered likely will remain clearly below the limit provided in the Government decree over the course of the next 10,000 years, even for the most exposed people, and the doses incurred by other people will remain negligible. It is estimated that, after this time, the releases of radioactive substances resulting from developments that are considered likely will, at most, remain under one-thousandth of the maximum values specified by STUK. Furthermore, based on an assessment of typical radiation doses, the radiation exposure of the current fauna of the final disposal site will remain clearly under the reference value proposed in international projects. The resulting radiation doses and release rates of radioactive substances have been assessed taking into account the possible random deviations from the operability requirements for the final disposal system as well as the uncertainties in the calculation models and initial data used in the assessment.

The conclusions presented above are justified in detail in the safety case documentation to be submitted to STUK. The results of the long-term safety assessment are presented in Appendix 5 to this application.

8.5 CLOSURE OF DEPOSITION TUNNELS

The deposition tunnels and central tunnels are backfilled after final disposal (installation of the canister and the buffer material), and the backfilling is carried out in stages throughout the operation of the plant. Furthermore, the disposal repository's technical facilities and connections to the ground surface, such as the driving tunnel and shafts, will be filled at the end of the final disposal operations.

The primary purpose of the backfilling and closure structures is to return the final disposal conditions as close to the natural state as possible, for example by preventing tunnels and shafts from becoming primary groundwater flow routes, and to prevent unauthorised access to the disposal repository.

8.6 EFFECTS ON GROUNDWATER

The disposal repository spaces are tightened with cement or silica injections, which keep the effects of the disposal repository on groundwater level to a minimum. Changes in pressure height are also limited by injecting all major leak points as efficiently as possible. Based on the experience obtained, even large changes in local groundwater pressure height cannot be completely avoided, because even small leaks have caused large reductions, especially near ONKALO, but in some places also several hundred metres away. This is because the structure related to the leaking section is limited and has no connections to the rock sections that produce replacement water. The total amount of leakage flows will be limited by the construction and closure of tunnels as final disposal canisters are placed in them; the rock volumes open at any given time during the operating phase will be minimised.

9 OVERSIGHT OF FACILITY

9.1 RADIATION MONITORING AT THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

During the operating phase, the encapsulation plant and disposal facility are divided into three separate areas: the radiation controlled area, monitored area and non-controlled area. Access to the radiation controlled area is controlled for reasons of radiation protection.

All handling of spent fuel and canisters always takes place in the radiation controlled area. The installation of bentonite blocks in deposition holes also takes place in the radiation controlled area. The encapsulation process will be monitored, underground facilities will be excavated and built and tunnels will be backfilled in the non-controlled area. Among others, the locker rooms and washrooms are located in the monitored area.

To keep the handling and installation conditions of the final disposal canisters clean, the ventilation in the radiation controlled area is separate from the ventilation in the non-controlled area. The radioactivity of the exhaust air in the radiation controlled area is measured, even though the air is not filtered in normal operating conditions. The filtering of the radiation controlled area ventilation is activated if radiation measurement detects radioactivity that exceeds a limit. In critical work stages, filtering can also be activated in advance. Air in the handling cell is being filtered continuously. Radon exposure is followed by monitoring radon concentrations and adjusting ventilation volumes in all disposal repositories.

9.2 ACCESS CONTROL AT THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

The purpose of access control is to track who is working in the encapsulation plant and disposal facility and where they are at any given time as well as to control access to various premises, such as the radiation controlled area or the non-controlled area. Modern computer-based surveillance systems are used for access control. In the case of radiation controlled facilities located deep in the bedrock, appropriate access control is not only a matter of corporate security but also a matter of personal safety.

Crossing the boundary between the controlled area and the non-controlled area underground is restricted with access arrangements in normal conditions. However, moving from the controlled to the non-controlled area or the other way around will be allowed as necessary in the event of an emergency, such as a fire.

Sufficient safety distances to dampen vibration from excavation shall be left between the tunnels to be excavated and the deposition tunnels containing canisters. Building materials, machinery, explosives and quarry material are transported through the driving tunnel. The final disposal canisters are transported through the canister shaft or, alternatively, through the driving tunnel. The clay materials for the deposition holes and tunnels are transported through the driving tunnel.

9.3 CONDITION MONITORING

The purpose of condition monitoring is to monitor the condition of the encapsulation plant and disposal facility and its systems during the operating phase. The condition of the encapsulation plant and disposal facility is monitored through measurements, periodic tests and inspections. The condition of the disposal repository is monitored by measuring the amount of leaked water, tension inside the rock and displacements in the disposal repository. The instrumentation system is also used to collect and process information on the condition of the disposal repository and ensure that occupational safety remains good in the disposal repository.

9.4 OVERSIGHT BY THE RADIATION AND NUCLEAR SAFETY AUTHORITY

The Radiation and Nuclear Safety Authority oversees the safety of the handling, storage and final disposal of nuclear waste according to the programmes for the construction phase (RTO) and operating phase (KTO). To ensure proper final disposal of spent nuclear fuel, the authorities have imposed specific reporting obligations on nuclear waste producers in the regulatory guides (YVL) for the construction and operating phases.

With the assistance of other expert organisations, the Radiation and Nuclear Safety Authority reviews the studies and technical plans for the safe final disposal of nuclear waste and provides feedback to the party implementing the project.

9.5 ENVIRONMENTAL RADIATION MONITORING PROGRAMME

The releases of radioactive substances from nuclear power plants, encapsulation plants and disposal facilities occur through monitored release routes. The total activity and nuclide concentration of the releases are measured. The direct measurement of the doses caused by the releases in the environment is impossible due to their small size when compared to natural background radiation and its fluctuations. The concentrations of radioactivity caused by the releases are measured by means of an environmental radiation monitoring programme

Figure 5. The Olkiluoto power plant area and its environment are closely monitored through studies.

that covers all of Olkiluoto and includes, among other things, determining the radioactivity concentrations of some 400 environmental samples each year.

The radiation and radioactivity in the environment of the Olkiluoto power plant are monitored according to a radiation monitoring programme that is updated at least once every five years. The updates in 2008 and 2009 added new sampling points that can be used to detect any releases that could be carried further to the sea due to the increase in cooling water flow caused by the Olkiluoto 3 plant unit. The radiation monitoring programme was last updated in 2018 in accordance with Guide YVL C.7. The measurement and sampling items are external radiation, air, rainwater, soil, garden products, natural plants, household water, landfill water, seawater and the local population. In addition, STUK is carrying out its own environmental radiation monitoring programme at Olkiluoto. STUK's monitoring programme includes, among other things, milk, grain, fishes, bottom sediment, periphyton, benthos and aquatic plants.

In 2018–2020, a radiological environment baseline study required by Guide YVL C.7 was carried out in the vicinity of Posiva's facilities. During the baseline study, environmental samples were collected for radioactivity measurements from places where possible releases into the air or water from Posiva's facilities could be observed. Among other locations, samples were taken along the disposal repository effluent ditch, from the sea where the effluent ditch is discharged and near the quarry material dumping area. The sampling items included rainwater, soil, natural plants, ditch water, groundwater, seawater, fishes, periphyton, settleable solids, bottom sediment, acquatic plants and benthos. According to the results of the baseline study, the environmental radioactivity levels near Posiva's facilities are equivalent to the rest of Olkiluoto.

During the operating phase of Posiva's facilities, Posiva and TVO will have a joint environmental radiation monitoring programme that involves the entire Group. Sampling and measurement locations that also cover Posiva's possible release routes will be added to TVO's currently valid radiation monitoring programme. For Posiva, the programme will take into account, for example, potential releases into the water that would travel along the ONKALO effluent ditch to the sea and releases into the air that would spread via the encapsulation plant's ventilation stack to the nearby surroundings. Posiva will report on the results of the environmental radiation monitoring programme to the Radiation and Nuclear Safety Authority according to a separate plan (at least annually).

9.5.1 ANALYSIS METHODS FOR ENVIRONMENTAL IMPACTS OF RADIATION

Established calculation models that have been approved by the Radiation and Nuclear Safety Authority have been used for estimating the travel of radioactive substances in water systems, the atmosphere and food chains. They can be used to estimate the radiation doses of the environment on the basis of measured and anticipated release amounts. The models take into account all the significant exposure routes through which radioactive substances from releases can enter the human body. The information concerning the environment and the living habits of the population that are required for the models have been analysed and selected to suit the environment at the facility site. The calculation of airborne travel uses meteorological measurement information that is produced by the continuously operating measuring instruments of the weather mast located at the facility site.

The actual conditions of the facility site and its surroundings cannot be completely described with the dose calculation models due to the high variation in the variables describing the environment and the living habits of the population. This is compensated for by selecting numeric values for the variables in the models that tend to increase the radiation dose calculated on the basis of the releases. This conservative approach that tends to overestimate the doses aims to ensure that the actual doses caused to the population are always smaller than the calculated values.

10 OTHER ENVIRONMENTAL IMPACTS

Other environmental impacts caused by the operating phase of the encapsulation plant and disposal facility include noise, waste, process water from the disposal facility, effects from the crushing of rock and dumping of quarry material (including dust, noise and vibration), effects on the groundwater pressure height and the storage and use of chemicals, explosive materials and liquid fuels in the facility area. The occurrence of these impacts is regulated by Posiva's environmental permit for crushing and storing quarry material and the permit for the industrial processing and storage of hazardous chemicals; noise is monitored according to the environmental permit for the Olkiluoto power plant area.

10.1 EFFECTS ON NATURA AREAS

The possible effects of the encapsulation plant and disposal facility on Natura 2000 areas have been examined already during the environmental impact assessment. The updated information is presented in Appendix 10 to this operating licence application, *"An updated analysis of the environmental impacts of the plant complex".* The status of the Natura area south of the encapsulation plant and the Liiklankari old-growth forest conservation area are followed as part of Posiva's monitoring programme. No harmful effects resulting from the encapsulation plant and disposal facility have been detected in the area's vegetation, surface water or groundwater.

10.2 ENVIRONMENTAL PERMITS AND OTHER PERMITS

According to the decision by the Regional State Administrative Agency for Southern Finland (ESAVI-0000426-05.14.00-2011, 19 Jan 2011), the encapsulation plant and disposal facility do not require an environmental permit. During their construction and operations, the spent nuclear fuel encapsulation plant and disposal facility require, for example, building permits, a permit for temporary storage of explosives and a permit for storage of quarry material. These permits will be applied for before the start of the related activity in accordance with the valid national and municipal regulations

11 CONCLUSIONS

Since the amount of spent nuclear fuel being processed at any given time is small and the principle of isolation is carefully followed, the radioactive releases during the operation of the encapsulation plant and disposal facility are so low that they will not impact the environment or the surrounding population. Even in very rare accident situations, the releases will be so small that sheltering will not be required of the population. The environmental impact from transports will be low during final disposal operations, as the traffic to Posiva's encapsulation plant and disposal facility comprises only a small portion of the Olkiluoto Island traffic (some 5% of the overall traffic volume). The environmental impact of exhaust gas emissions resulting from the transports of spent fuel is insignificant due to the small number of transports. The radiation dose to the population in connection with the transports is considerably lower than the dose incurred from natural background radiation in the same period.

The operations of the encapsulation plant and disposal facility are not considered to be unreasonably detrimental to the water systems in the region. The environmental impact of the operation of the encapsulation plant and disposal facility will be followed by means of monitoring programmes, and the results will be reported to the regulatory authorities in the manner required by the monitoring programmes. The environmental impacts of the nuclear facility and the implementation of its monitoring programme will also be evaluated in connection with the renewal of the operating licence and, as necessary, the review of the environmental permit for the dumping of quarry material.

07

REPORT ON THE EXPERTISE AVAILABLE TO THE APPLICANT AND THE OPERATIONAL ORGANISATION OF THE NUCLEAR FACILITY

Photo: Posiva Oy

TABLE OF CONTENTS

1 ADMINISTRATIVE BODIES AND COMMITTEES

The company has a Board of Directors consisting of representatives appointed by the Annual General Meeting.

Posiva's Board of Directors appoints a project committee, finance committee and technical committee annually. The term of office of the chairs of the committees is two years, and the chair alternates between the owner companies. The aim is for committee members to be able to oversee and direct management during both the current construction phase and the future production phase, and also to prepare significant decisions to be taken to the Board of Directors.

2 GENERAL MANAGEMENT

Posiva's operations are managed by the President and CEO, who is the direct supervisor of the Safety Manager, Development Manager, Project Manager, Construction Manager, Technical Manager and Production Manager during the construction phase. The President and CEO is assisted by a management team in planning, implementing, evaluating and developing operations. In addition to the President and CEO and the above-mentioned persons working directly under him, a representative of Posiva's personnel; TVO's Communications Manager; TVO's Resource Manager/HR Partner; and the CEO of Posiva Solutions Oy also participate in the work of the management team. Posiva Solutions Oy is integrally connected to the Posiva organisation.

During the production phase, the production, concept, plant engineering, construction and safety functions operate under the direct supervision of the President and CEO. The business partners responsible for TVO's service operations at Posiva also operate under the President and CEO. The President and CEO is responsible for the company's operations and results to the Board of Directors.

The project organisation during construction consists of programmes and the projects operating under them, as well as separate projects operating outside the programmes. Encapsulation plant, disposal facility, canister, buffer, backfilling and sealing, safety case, final disposal production equipment and preparation for production have been named as programmes. The steering and oversight of the programmes is the responsibility of the steering groups separately appointed for each programme and their chairs. Operating licence and monitoring have been named as separate projects. Posiva acts as the contractor in all programmes and projects, and it thus has overall responsibility for both design and implementation. As contractor, Posiva procures design and implementation from outside parties if necessary.

For the management and coordination of cross-functional tasks or topics, the company's management has set up working groups that include representatives from different organisation units. These include the following, for example:

- Safety group
- Engineering group
- Plant meeting
- Long-term Safety group
- Safety Culture group.

Posiva is also involved in various working groups of the TVO Group, such as:

- ALARA group (radiation safety)
- CAP (Continuous improvement of operations) group
- Infrastructure and Land Use steering group
- Ageing Management group
- Operating Experience group
- Risk Management group
- Information Security group
- Data Administration group.

If necessary, different groups of experts can be convened to deal with specific issues. The purpose of these groups is to simplify the processing of matters and to promote information transfer and cooperation across the boundaries of organisation units.

3 GENERAL DESCRIPTION OF THE ORGANISATION

The operating line organisation and nuclear safety organisation of the encapsulation plant and disposal facility and their management relationships, tasks, authorities and qualification requirements are presented in the administrative rules of Posiva Oy, as required by Section 122 of the Nuclear Energy Decree (12 February 1988/161). In addition, the administrative rules present the responsible managers referred to in Section 7 k of the Nuclear Energy Act and their deputies and the persons responsible for emergency preparedness arrangements, security arrangements and nuclear safeguards referred to in Section 7 i of the Nuclear Energy Act and their tasks, authorities and responsibilities. The administrative rules take into account the responsibilities and management relationships during operation. The Radiation and Nuclear Safety Authority approves the administrative rules. Figure 1 shows Posiva's basic production phase organisation.

The aim of human resource management is to ensure that Posiva has at each stage of final disposal a properly sized and targeted personnel to achieve its strategic goals. During operation, Posiva has an organisation that takes care of the following functions among others:

- nuclear, long-term and radiation safety and nuclear material management
- management, development and maintenance of the final disposal concept
- preparing and maintaining safety assessments
- managing permits
- design functions and maintenance of technical systems
- construction
- corporate planning
- procurement and logistics
- operation and maintenance
- corporate safety (security and emergency preparedness arrangements as well as fire safety, occupational safety and information security)
- quality and environment
- support functions such as human resources, training, law, finance, data administration and communications.

Posiva's organisation and the tasks of the organisation units have been presented in more detail to the supervisory authority (STUK) for information.

3.1 ORGANISATIONAL FUNCTIONS

Safety

The Safety function acts as an expert and control organisation for nuclear safety, quality

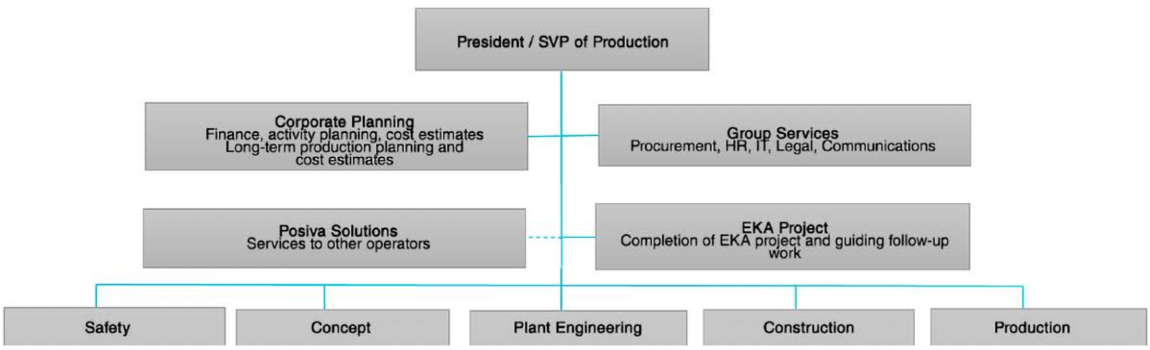


Figure 1. Posiva's basic production phase organisation.

management, quality control and corporate safety. The task of the Safety function is to ensure that Posiva's activities meet the requirements set for safety and high-quality operations. The tasks of the Safety function include the coordination of regulatory issues in the field of nuclear energy, contacts with the authorities and licensing, as well as taking care of emergency preparedness arrangements and corporate safety. The function also takes care of the administrative tasks of the Safety group and coordinates the activities of Posiva's Safety and Safety Culture groups.

The activities of the Safety function are managed by the Safety Manager, who reports to the President and CEO and serves as a member of the management team.

Concept

During the production phase, the Concept function is responsible for managing the long-term safety of the final disposal, for the Olkiluoto site monitoring programme and for analysing the monitoring results. This will be done through operational procedures; periodic safety assessments; and research and development programmes aimed at optimising the final disposal concept, reducing uncertainties in the safety case and streamlining operational processes. Operational procedures include the design and implementation of research, monitoring and control programmes; rock suitability classifications; and the long-term safety-critical functions related to final disposal. The function is also responsible for the development of technical release barriers as part of the final disposal system, technical support for procurement and the management of design bases.

The Concept function is managed by the Development Manager, who reports to the President and CEO and serves as a member of the management team.

Plant Engineering

The Plant Engineering function is responsible for the various systems of the plants, the planning of their expansion and modification work, the layout planning of the disposal facility and the thermal engineering dimensioning of the plant. The task of Plant Engineering is to take care of the modification work process and to maintain the plant configuration. The function also takes care of the service life management and technical maintenance of the plants, so that the plants can be used safely at all stages of their service life.

The Plant Engineering function is managed by the Technical Manager, who reports to the President and CEO and serves as a member of the management team.

Construction

The Construction function is responsible for construction, and for ensuring that construction during the production phase does not endanger the operation and long-term safety of the plant. Construction includes all functions related to the construction of the disposal facility during the production phase, including the necessary construction, manufacturing, installation and commissioning work, as well as the implementation of rock suitability classification and monitoring. For construction and excavation work, Posiva will mainly use external resources. The Construction function also acts as an expert unit in rock construction technology.

The Construction function is managed by the Construction Manager, who reports to the President and CEO and serves as a member of the management team.

Production

The Production function is responsible for the practical implementation of the final disposal process. The function includes the functions of operation, maintenance, operational support (including nuclear safeguards and radiation protection) and production process development. The Production function is responsible for the operation of the nuclear facility in accordance with legislation, permits, regulations and guidelines.

The Production function is managed by the Production Manager, who reports to the President and CEO and serves as a member of the management team. The Production Manager will also serve as the director responsible for operation.

The operating organisation belonging to the Production function is responsible for all operational activities at the nuclear facility, monitoring, inspecting and controlling the day-to-day matters related to the operation of the facility that fall within its area of responsibility. Operation is responsible for the management of work permits; the coordination of spent fuel transfers and the maintenance of the fuel database; the plant's operating instructions; the management of waste generated during operation; and functions related to chemistry and radiation protection.

Decisions on the operation of safety-critical systems and equipment and their implementation are primarily the responsibility of the Production Manager and the Operations Manager, who also acts as the head of the work permit office. The process controllers manage the encapsulation and final disposal process from the control room under the management of the work permit office, ensuring that all functions are carried out in accordance with the operating instructions, orders and work permits.

The maintenance organisation, which is part of the Production function, takes care of the maintenance of the nuclear facility. It includes the maintenance of machinery and equipment as well as facilities, buildings and systems.

The most important groups that supervise and guide operation are the Safety group, the plant meeting and the Safety function. The purpose and tasks of the groups are defined in the administrative rules.

Corporate Planning

The Corporate Planning function is responsible for finances, operational planning, the company's general cost estimates as well as PTS production planning and cost estimates.

The activities of the Corporate Planning function are managed by the Corporate Planning Manager, who reports to the President and CEO and serves as a member of the management team.

4 JOINT ACTIVITIES OF THE TVO GROUP

Posiva is part of the TVO Group, and in order to ensure competent and sufficient resources for Posiva's use and enable efficient and flexible use of resources at the same time, it will also utilise the Group's human resources in the organisation of the production phase. The work input of human resources in an employment relationship with TVO and working for Posiva is procured through the TVO-Posiva service agreement.

The following describes TVO units which will be utilised in the production phase by Posiva among others:

Maintenance

The unit includes the following teams:

- OL1/OL2 Mechanical Maintenance
- OL1/OL2 I&C Maintenance
- OL1/OL2 Electrical Maintenance
- OL3 Mechanical Maintenance
- OL3 I&C Maintenance
- OL3 Electrical Maintenance
- Property Maintenance
- OL1/OL2 Work Planning
- OL3 Work Planning
- Maintenance annual outage planning
- Development of maintenance

The unit is functionally divided into three parts: OL1/OL2 maintenance, OL3 maintenance and Maintenance support. The maintenances have their own maintenance managers and maintenance support has a development manager. The individuals are responsible for the operations of the teams in their own function. The unit manager is responsible for maintenance activities as a whole.

The task of the unit is to manage the preventive maintenance, condition monitoring, repairs and modifications of the buildings, premises, mechanical, electrical and I&C equipment, process computer equipment and systems in the Olkiluoto area. The unit is also tasked with participating in the design and implementation of structural changes.

Fuel

The unit takes care of TVO's nuclear fuel throughout its lifecycle, i.e. from procurement of uranium until the final disposal of the fuel elements. This includes the procurement of fuel, the planning of its transportation, handling, use, calculation, inspections and storage, as well as ensuring and monitoring the implementation of these. Posiva's operations utilise the services of a fuel engineer and nuclear safeguards.

Production Support

The unit includes the following teams:

- Radiation protection
- Chemistry
- Fuel and waste handling

The task of the unit is to take care of the planning, implementation and supervision of the functions related to power plant chemistry, radioactivity measurements, radiation monitoring and environmental research and control that is the responsibility of the Electricity Generation business; to take care of the planning, implementation and supervision of radioactive waste management measures; and to participate in the planning, implementation and monitoring of fuel processing measures.

The unit is responsible for decontamination tasks, laundry operations and the operations, control, reporting and development of sanitation and waste management in the radiation controlled area and other designated areas.

The unit is responsible for decontamination tasks, laundry operations and the operations, control, reporting and development of sanitation and waste management in the radiation controlled area and other designated areas.

Engineering

The Engineering function acts as a technical expert organisation for the operation of the Olkiluoto power plant units and nuclear facilities, as well as for the implementation of plant units/ facilities under construction or being planned.

The function is responsible for ensuring that the Group's business operations have sufficient technical support for the continuous financial optimisation and lifecycle management of the nuclear facilities' structures and systems in compliance with safety regulations.

The Engineering function consists of the following units:

- Engineering control
- Plant modifications
- I&C engineering
- Electrical engineering
- Power plant engineering
- Construction engineering
- Nuclear safety engineering

The performance of the function's tasks requires the efficient use of both the Group's own and external resources, the utilisation of external experience and the monitoring of technical developments in the nuclear power sector. The general task of the units is to ensure competence in the area of responsibility, its development and the optimal acquisition of external human resources, as well as the optimal use of persons and competence.

Safety

The task of the function is to take care of the preparation, implementation or coordination of implementation of programmes and plans necessary to ensure nuclear safety, quality management, quality control, corporate safety and nuclear safeguards at the company's nuclear facilities; to analyse events or conditions that affect or compromise nuclear safety or availability; and to monitor the implementation of necessary remedial measures.

The function is also responsible for independently monitoring the implementation of structural changes and compliance with the general design principles and safety analyses of nuclear facilities, and for taking care of the permits for nuclear facilities required by the Nuclear Energy Act. The function is also responsible for, and takes care of the operations of, the company's inspection body.

The Safety function includes the following centres of excellence and areas of responsibility/ equivalent:

- Nuclear safety centre of excellence
- Corporate safety centre of excellence
- Fire, occupational and environmental safety, as well as security and emergency preparedness arrangements
- Quality management centre of excellence
- Quality control centre of excellence
- Person responsible for nuclear safeguards
- Safety research and development managers

Support Services

The Support Services functions provide the support services needed by all business and service units in the TVO Group and are responsible for the related policies and performance.

The managers of the Support Services functions are responsible for providing support services to business and service operations and for the performance of the services for which they are responsible.

The heads of the centres of excellence are fully responsible for the management, organisation and resourcing of their own support function, and participate in the development of the operating model of support functions and the search for synergies.

The managers of the service centre functions are responsible for the organisation and resourcing of their own service centre unit.

Designated Business Partners support business management in strategic, tactical and operational planning, decision-making and implementation from the perspective of their own functional expertise.

5 REPORT ON THE EXPERTISE AVAILABLE TO POSIVA OY

5.1 POSIVA'S PERSONNEL POLICY

At Posiva, staff development is seen as an investment in safe and high-quality operations in the future too. At Posiva, personnel policy follows the principles of the management system and the strategic priorities. One of Posiva's vision elements is "good work community", which highlights the following vision goals:

- The leadership and company culture promote doing the right things in order to reach the mutual goals – the company has a good atmosphere
- The competencies and skills necessary for implementing the strategy have been defined and are available
- Committed and dedicated persons are doing the right things.

At Posiva, the principle has been to develop personnel development methods and training activities in such a way that it enables

the maintenance of the competence of the personnel as well as continuous learning and development. In the organisation, competence is committed not only to people but also to ways of working. The operations of the nuclear power plant are governed by numerous guidelines and conditions, the most important of which have also been approved by the regulatory authority.

The company has in force contracts concerning expert services with several domestic and international parties. Regular assessments are arranged in order to determine the expertise and competence of suppliers.

Posiva has participated, and continues to participate, in several national and international development programmes in the field of final disposal of spent nuclear fuel. This allows the company to receive more information concerning developments in the field and to maintain functional contacts with experts in the field. Representatives from the company take an active role in the operations of domestic and international organisations in the energy and nuclear energy industries.

Figure 2. In addition to its own personnel, Posiva has a wide-ranging network of experts with its owners and consulting firms.

Posiva also intends to make use of TVO's WANO membership in utilising the operating experiences of nuclear facilities and nuclear waste facilities.

Posiva and SKB (Svensk Kärnbränslehantering Ab) have continued their close cooperation with a common goal to finalise the final disposal concept and to prepare for the industrial-scale operation of the disposal facility. Posiva has resumed its cooperation with the International Atomic Energy Agency IAEA, the OECD/NEA nuclear waste office, the International Association for Environmentally Safe Disposal of Radioactive Material (EDRAM) and the Club of Agencies, a cooperative group of more than 20 waste organisations from Europe.

5.2 PERSONNEL AND TRAINING

The number of people employed by the company on 31 December 2020 was 87, including permanent and fixed-term employment relationships. During the year, Posiva employed an average of 90 people, of whom 92% have a technical or scientific background: among others, 12 doctors and licentiates, 21 qualified engineers, 16 engineers, 2 technicians and works engineers. Alongside the employees with a background in technology or natural sciences, the company employs persons with financial or legal expertise in the nuclear industry.

In addition, approximately 40 TVO employees are working on Posiva's project from 50% to 100%. The number of personnel at Posiva Solutions at the end of the year was 5.

The goal of personnel development and training activities at Posiva is to ensure and maintain the competence (know-how, skill and attitudes) of the personnel and of external resources that is required in the nuclear field. Among other things, a high level of competence is achieved through training requirements targeted at different functions, competence mapping, job rotation, familiarisation and job guidance. Prior to commencing operation, Posiva verifies the competence of the personnel in the tasks assigned to them, which the Radiation and Nuclear Safety Authority also reviews in its safety assessment of the operating licence application.

The training provided within Posiva must match the personnel development priorities derived from the company's strategy, the requirements in accordance with the official guidelines and other requirements set for the performance of duties. The meeting of these requirements is followed as part of the supervisor activities and in a coordinated manner at the company level.

The personnel of Posiva affect the safety of the nuclear facilities either directly or indirectly. Therefore, it must be ensured that every person understands the safety significance of his/her task and is qualified for the position. The qualification requirements are based on the actions pursuant to a good safety culture that are expected of the entire personnel, and the work tasks and areas of responsibility that have been defined for the task.

Subcontractors must also commit to Posiva's ways of working and act in accordance with the practices set out in the training. The subcontractors' supervisors and foremen are responsible for the subcontractor qualifications, and they are also responsible for familiarising the person with the work tasks and referring them to additional training, if necessary.

The individual training plans defined for Posiva's personnel consist of function-specific training; training required for special roles and permissions; training required for familiarisation and job guidance; and other supplementary and further training defined with the supervisor.

The purpose of systematic familiarisation and job guidance is to provide a new employee or an employee switching tasks within the TVO Group with sufficient information regarding the Group as a company, the working environment, terms of employment, work tasks and expectations in order to allow them to work individually within the work community.

As a tool for personnel development and training planning, the TVO Group has an annual training programme at its disposal, the purpose of which is to build a comprehensive training programme to maintain and develop personnel competence using resources in a centralised and planned manner. The training needs of TVO and Posiva are systematically compiled every year into the annual training programme. The framework is formed by training requirements that are function-specific or related to special roles or permits, which are supplemented by training proposals received from various stakeholders such as organisations, the Operating Experience group (KÄKRY) and the quality management information system (KELPO). The annual training programme includes the following main subject areas:

- General engineering
- Nuclear engineering
- Plant engineering
- Operational engineering
- Maintenance
- Protection and emergency preparedness
- Administration and finances
- ICT
- Cooperation and communication
- Other training

Posiva utilises the expertise of its owners and other long-term partners and subcontractors, but retains within its own organisation the key responsibilities required for the safe operation of final disposal.

By systematically investing in the competence of the personnel and its maintenance, the professionalism of the personnel represents in Posiva's view the expertise required to perform the tasks related to the nuclear facility.

Posiva trains its personnel and subcontractors especially on the special features, ways of working, safety culture and technology of the nuclear facility.

Table 1 shows the number of training hours and days for Posiva's employees in 2020.

Table 2 shows the distribution of internal training days for Posiva's employees in 2019 and 2020 divided by theme.

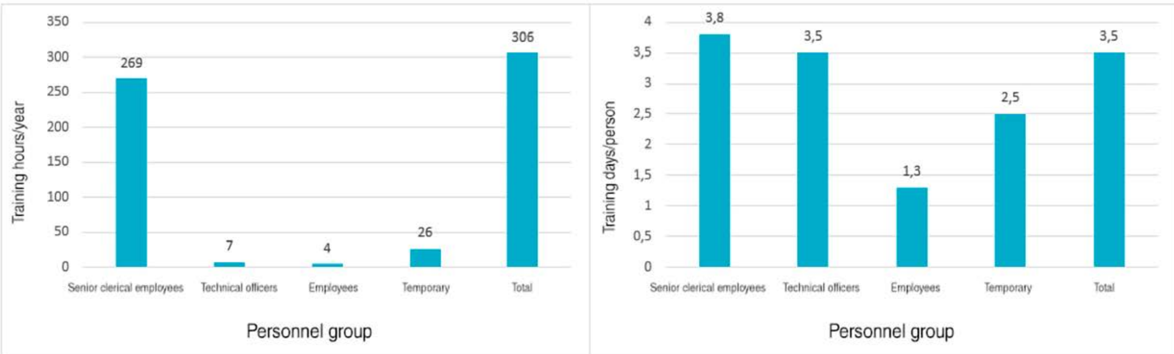


Table 1. Distribution of training hours and days by Posiva personnel group, 2020

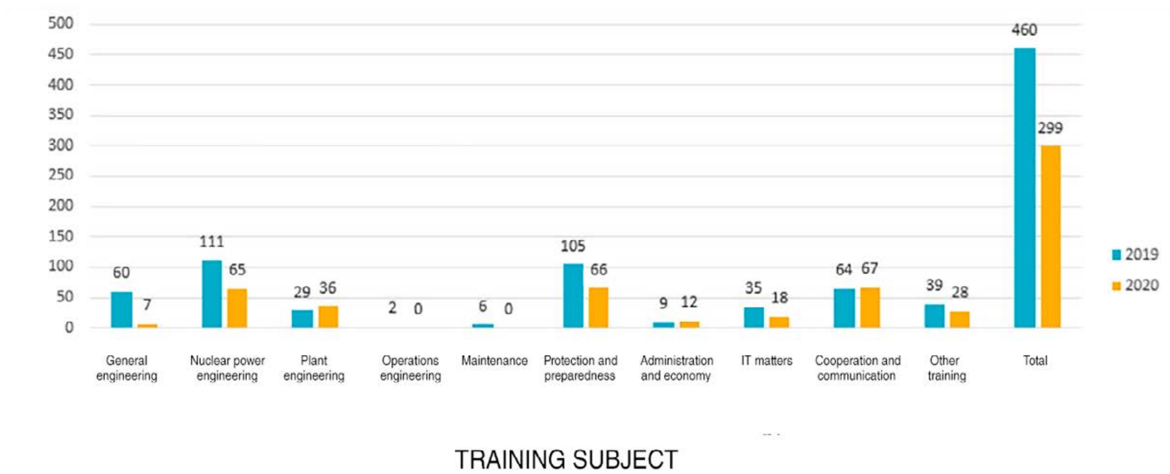


Table 2. The internal training days for Posiva's employees in 2019 and 2020 divided by theme.

6 SAFETY AND SAFETY CULTURE

Safety culture consists of the features and attitudes of the organisation and of individuals, as a result of which all factors that affect the safety of nuclear facilities will receive attention in proportion with their significance and are given priority in decision-making. A good safety culture must be maintained in all of Posiva's operations. This means that

- management demonstrates its commitment to safety-enhancing ways of working and solutions through its decisions and actions
- personnel are motivated to work responsibly
- in the work community, an open atmosphere is promoted that encourages the identification, reporting and elimination of threats to safety
- staff have the opportunity to contribute to the continuous improvement of safety.

Posiva has its own Safety Culture group, which is represented in the TVO Group's corresponding CAP group. Conversely, TVO's safety culture expert is also involved in Posiva's Safety Culture group. Posiva's Safety Culture group prepares an annual safety culture action plan, which includes general areas for development and objectives for a period of three years and a more detailed action plan with objectives for each year.

The implementation of the principles of safety culture is assessed annually in the Safety Culture group's assessment of the state of Posiva's safety culture, which is presented to Posiva's management team and Safety group.

As part of the safety culture action plan for 2020–23, Posiva's Safety function monitored safety in accordance with the management system. The company's safety culture action plan 2020 was implemented without major deviations, although preventing the effects of COVID-19 had some effect on the implementation. Posiva carried out a self-assessment of the management system and safety culture in 2020; the results were good and showed improvement since the last assessment. The level of safety and safety culture at Posiva in 2020 was good.

08

REPORT ON THE APPLICANT'S
FINANCIAL STANDING,
FINANCING MANAGEMENT PLAN FOR
THE NUCLEAR FACILITY
AND PRODUCTION PLAN FOR THE
NUCLEAR FACILITY

Photo: Posiva Oy

COST ESTIMATE AND FINANCING PLAN FOR THE NUCLEAR FACILITY PROJECT

THE COMPANY'S FINANCIAL STANDING

The operating preconditions of Posiva Oy are determined by the relations between Posiva and its owners, as defined by agreements. According to the Nuclear Energy Act, the owners are responsible for the spent nuclear fuel of their plant units, and for matters such as the cost of its final disposal. Posiva will implement the final disposal and charge the costs to the owners.

Posiva's 2021 cost estimate for the final disposal of spent nuclear fuel is based on the YJH-2018 programme, the plant description from 2018 and the cost estimate prepared based on them. The cost estimate is based on the spent nuclear fuel generated by the Loviisa 1, Loviisa 2, Olkiluoto 1, Olkiluoto 2 and Olkiluoto 3 plant units during their entire service life, estimated as accurately as possible to be a total of approximately 5,500 tonnes of uranium (tU). The cost estimate has been prepared at the 2018 price level. It is estimated that the final disposal will cost a total of approximately EUR 3,520 million. Of this, the construction of ONKALO® and the encapsulation plant and disposal facility accounts for approximately EUR 840 million. The cost of operation, including encapsulation and the canister materials, as well as the backfilling of the deposition holes and tunnels with materials and the backfilling of central tunnels, is approximately EUR 2,575 million. The cost of decommissioning the encapsulation plant and closing the disposal repository is approximately EUR 105 million. In addition, costs have been and will be incurred for pre-implementation and in-service research work, administration, taxes and regulatory oversight. The costs span approximately one hundred years.

Posiva's financial operating conditions are discussed in the annual reports, which are published on Posiva's website. To finance the costs of operating the encapsulation plant and disposal facility, the same general principle applies which has been used to finance research and development and the construction of ONKALO® and the encapsulation plant and disposal facility: Posiva charges to its owners the costs of performing its tasks, in accordance with the agreements made.

To ensure resources for nuclear waste management in all circumstances, the State Nuclear Waste Management Fund collects funds from the nuclear waste producers in advance. The amount of the fund covers the costs of all outstanding nuclear waste management measures. The fund is administered by the Ministry of Economic Affairs and Employment. The fund's capital consists of the annual fees of the waste producers and the fund's capital income. The actual waste management plans for the next 3 years, which include liability estimates, are updated every three years, and updated as necessary in the intervening years. The share of Posiva's owners in the fund's capital at the end of 2021 is approximately EUR 2,600 million.

COMPANY SHAREHOLDERS

The company is owned by Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat (FPH). TVO owns approximately 60% of the shares in Posiva, and FPH approximately 40%. According to the articles of association, Posiva's shareholders are responsible for the variable and fixed annual costs.

FINANCIAL CONDITION AND FINANCING PLAN OF THE COMPANY

Information on the company's financial condition is available in the financial statements found in the company's annual reports for 2010–2020, which are included in Appendix 11. The annual reports are available on Posiva's website. In order to guarantee the financial condition of the company's operations, the company's owners have collected funds to cover the costs of final disposal in the State Nuclear Waste Management Fund.

PRODUCTION PLAN

Posiva's production can be measured in terms of the amount of encapsulated spent nuclear fuel. The timing of production and the amount of different fuels to be placed in final disposal is determined by the cooling of the spent fuel. For safety reasons, spent fuel must be cooled in interim storage before final disposal. Posiva's production plan for the operating licence period applied for is described in Figure 1.

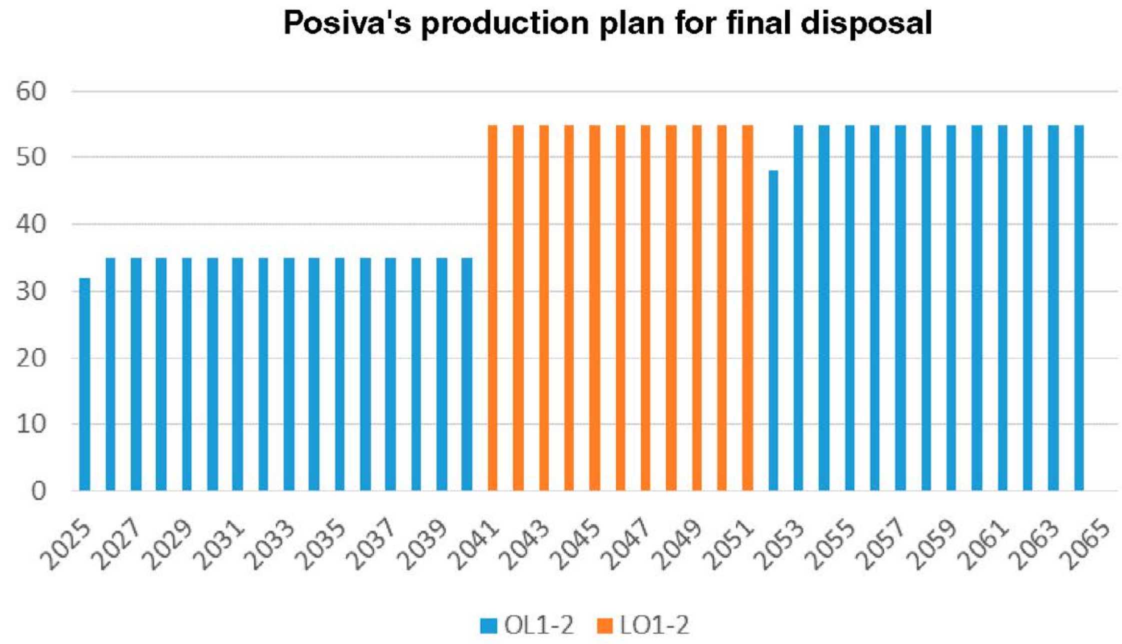


Figure 1. Posiva's productive final disposal plan for the first forty years. The figure shows how many final disposal canisters are placed in final disposal annually.

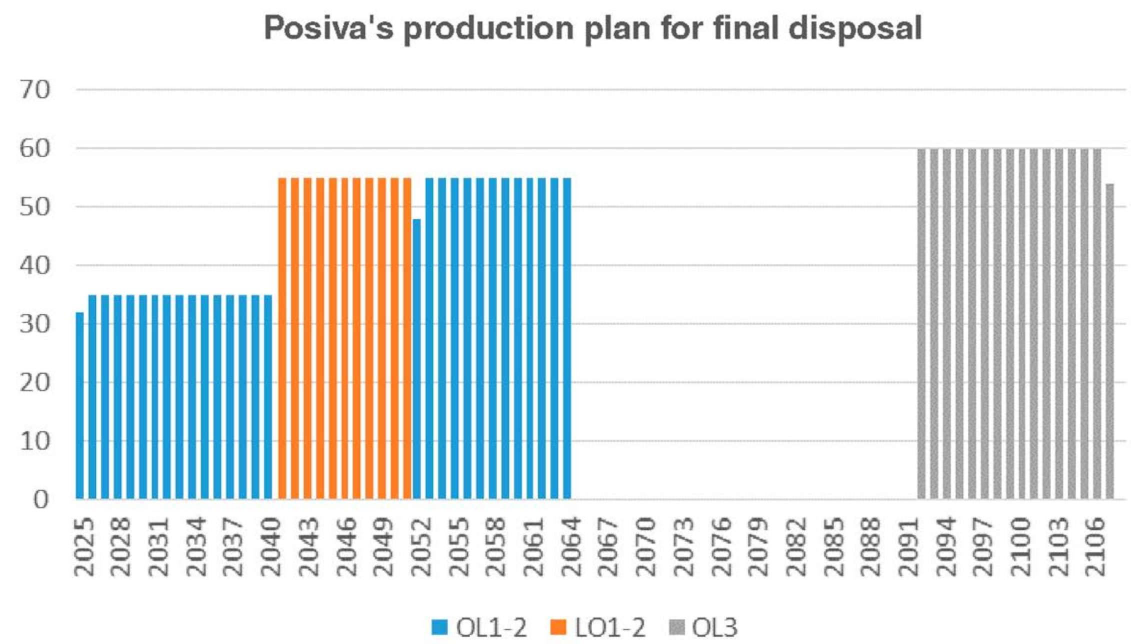


Figure 2. Posiva's operating activities will continue until the 2120s. The figure shows one possible production plan, in which approximately 35 final disposal canisters per year will be placed in final disposal initially, and later 55 to 60 canisters per year. The final disposal of spent nuclear fuel from the Olkiluoto 3 plant unit will start after it has cooled sufficiently in interim storage.

The final disposal of spent nuclear fuel is planned to continue until the 2120s. An example of Posiva's production plan for the final disposal of all spent nuclear fuel generated before the decommissioning of the nuclear plants is shown in Figure 2. Posiva's final disposal operations from the 2060s to the 2090s have a period of limited production before the final disposal of fuel from the OL3 plant unit. During limited production, the intention is to place in final disposal specialty fuels and modernise the plant and facility to ensure their service life. During this time, the fuel from the OL3 plant unit will cool in the spent fuel interim storage (KPA) to make final disposal safer and more sensible to start in terms of production. The limited production period also allows for extending the service life of existing plant units. The final disposal operations cover such a long period that other possible final disposal plans have also been prepared and will be prepared during the final disposal operations. Figure 2 shows an example of one of the most efficient production plans, which has optimised the final disposal rate, among other things.

09

THE APPLICANT'S FINANCIAL STATEMENTS FROM 1999–2015

The annual reports of Posiva Oy can be found on the company's website, posiva.fi.

10

UPDATED REPORT ON THE ENVIRONMENTAL IMPACTS OF THE PLANT COMPLEX

A report on the environmental impacts of the spent nuclear fuel encapsulation plant and disposal facility and an account of the design basis which the applicant intends to follow in order to avoid environmental damage and limit the environmental load

■ **Photo:** Posiva Oy

TABLE OF CONTENTS

1 PREFACE

Posiva Oy (hereinafter “Posiva”) carried out an environmental impact assessment procedure (EIA procedure) concerning the construction of a spent nuclear fuel encapsulation plant and disposal facility in 1997–1999, which comprised the spent nuclear fuel final disposal need of six nuclear power plant units (9,000 tonnes of uranium, tU). The information in the EIA was updated in 2008 for the decision-in-principle application concerning the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit. During 2008–2009, Posiva also carried out an entirely new EIA procedure which reviewed the expansion of the final disposal capacity of the planned encapsulation plant and disposal facility from 9,000 tonnes of uranium to 12,000 tonnes of uranium for the Loviisa 3 plant unit. The new EIA report was included as an appendix in Posiva’s decision-in-principle application concerning the final disposal of spent nuclear fuel from the Loviisa 3 plant unit.

In 2010, the Finnish Government issued favourable decisions-in-principle for the construction of the Olkiluoto 4 plant unit and for the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit at Olkiluoto. The Finnish Parliament kept these decisions-in-principle in effect. With regard to the Loviisa 3 plant unit construction project and the final disposal of its spent nuclear fuel, the Finnish Government has stated in the decisions-in-principle it has issued that the construction of the Loviisa 3 plant unit and the construction of the nuclear fuel disposal facility at Olkiluoto with an extension such that the facility would allow the processing and final disposal of the spent nuclear fuel generated during the operation of the Loviisa 3 nuclear power plant unit are not in the overall interest of society.

On the basis of the decisions-in-principle issued by the Finnish Government on 21 December 2000 and 17 January 2002, no more than 9,000 tU of spent nuclear fuel can be placed in final disposal at Olkiluoto.

In 2015, the decision-in-principle concerning the Olkiluoto 4 plant unit expired due to the termination of the Olkiluoto 4 project. In connection with this, Posiva’s decision-in-principle for the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit expired. Therefore, Posiva’s construction licence in November 2015 was issued for the final disposal of 6,500 tU of spent nuclear fuel, which corresponds to the amount of spent nuclear fuel from the OL1–3 and LO1–2 plant units. Posiva is now applying for an operating licence for this amount.

This report is an updated analysis of the environmental impacts of the spent nuclear fuel encapsulation plant and disposal facility, which examines the final disposal of 6,500 tU of spent nuclear fuel. The report contains up-to-date information on the environmental impacts of the encapsulation plant and disposal facility and the design basis which Posiva intends to follow in order to prevent environmental damage and limit the environmental load. The report has been prepared based on the knowledge which is currently available on the encapsulation plant and disposal facility, its location, the properties of spent nuclear fuel and its behaviour in the disposal repository.

The environmental impacts of the final disposal project have been reviewed extensively. The focus is on impacts that are estimated and considered to be significant. The significance of the environmental impacts has been assessed on the basis of the housing and natural environment in the review area, for example, and by comparing the tolerance of the environment in terms of each environmental load.

2 SUMMARY

The operation of the spent nuclear fuel encapsulation plant and disposal facility is subject to an operating licence issued by the Finnish Government. This report comprises an up-to-date account of the environmental impacts of the encapsulation plant and disposal facility project, which will be appended to the operating licence application that Posiva will submit to the Finnish Government. The account is based on 6,500 tU of spent nuclear fuel and on the level of knowledge in 2021 concerning the final disposal operations and their environmental impacts. The impacts of the project have been reviewed extensively when assessing environmental impacts. The focus is on impacts that are estimated and considered to be significant. The previous update of the environmental impact assessment report was submitted to the Finnish Government as part of Posiva's construction licence application.

Posiva, which is a company owned by Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy (Fortum), conducts research related to the final disposal of its owners' spent nuclear fuel, the construction and operation of the encapsulation plant and disposal facility, and the closure of the facility after operation ends. Furthermore, Posiva offers expert services in nuclear waste management to its owners and other customers via Posiva Solutions Oy.

3 PURPOSE, LOCATION AND SCHEDULE OF THE PROJECT

Posiva was issued a construction licence for constructing a spent nuclear fuel encapsulation plant and disposal facility at Olkiluoto, Eurajoki in November 2015. In accordance with the conditions of the construction licence, Posiva started the construction of a nuclear facility in the disposal facility in December 2016 and, therefore, the construction licence is valid. The spent nuclear fuel will be placed in final disposal in the bedrock of Olkiluoto in a disposal repository excavated at the depth of 400–450 metres. For this purpose, an encapsulation plant will be constructed; the spent nuclear fuel encapsulated at this plant will be transferred using a canister lift to the disposal facility for placement in final disposal.

During 2013–2024, detailed implementation plans required for the encapsulation plant and disposal facility have been made, industrial solutions for final disposal have been optimised, systems have been qualified, and the encapsulation plant and disposal facility will be constructed. Furthermore, the operating organisation and its functions have been planned, including the emergency preparedness and security arrangements. The operating licence application will be submitted such that the readiness to start final disposal will exist approximately in 2024. According to the current plans, the final disposal would end approximately in 2120.

4 CONNECTIONS TO OTHER PROJECTS AND PLANS

At Olkiluoto, Eurajoki, TVO has two boiling water reactors (the OL1 and OL2 plant units), each of which has a nominal electric power of 890 MWe (net), and a pressurised water reactor (the OL3 plant unit), whose nominal electric power is approximately 1,600 MWe (net). After the 2021 annual outages, the Olkiluoto power plant had in storage a total of 9,728 spent nuclear fuel elements, containing approximately 1,629.5 tonnes of uranium (tU).

Fortum's Loviisa nuclear power plant units Loviisa 1 and Loviisa 2 (LO1 and LO2) are located on Hästholmen island in Loviisa, some 80 km east of Helsinki. At the Loviisa power plant, there are two pressurised water reactors, each of which has a nominal electric power of 496 MWe (net). After the 2021 annual outages, the Loviisa power plant had in storage a total of 6,807 spent nuclear fuel elements, which is equivalent to approximately 794 tonnes of uranium.

5 DESCRIPTION OF THE FINAL DISPOSAL SOLUTION

The purpose is to place the spent nuclear fuel accumulated at TVO's nuclear power plants at Olkiluoto and Fortum's nuclear power plants in Loviisa in the spent nuclear fuel disposal facility; this disposal is intended to be permanent. The spent nuclear fuel can be isolated from the living nature by placing it in final disposal in bedrock at a depth of approximately 430 m inside sealed copper canisters with a spheroidal graphite cast iron insert. The hundreds of meters of depth ensures sufficient insulation from the effects caused by future ice ages.

Posiva's final disposal solution is based on a principle solution known as KBS-3, which has been developed by Svensk Kärnbränslehantering AB (SKB), the company responsible for Swedish nuclear waste management. The long-term safety concept of the final disposal solution is based on the multi-barrier principle, i.e. several redundant release barriers, such that the reduced performance of any single release barrier does not compromise long-term safety.

The engineered release barriers include the canisters, the surrounding clay buffer that protects them from bedrock movements and potentially corrosive substances in groundwater, and the deposition tunnel backfill material, which supports both the buffer and the rock. Furthermore, the buffer and deposition tunnel backfilling restrict the flow of groundwater in canister surroundings. The release barriers also include other components, such as the backfilling of other facilities as well as the plugs and closures of deposition tunnels, central tunnels, shafts, driving tunnels and research holes. They are designed to be compatible with the canister, buffer, deposition tunnel backfilling material and bedrock and to support their safety functions.

5.1 CONFIRMING RESEARCH STAGE

The research stage whose primary objective has been to study the bed-rock and obtain information on the final disposal site's properties for detailed planning of the encapsulation plant and disposal facility is called the confirming research stage. For this purpose, ONKALO® , an underground research facility that extends to the final disposal depth, was built at Olkiluoto.

ONKALO has comprised a spiral driving tunnel, personnel and ventila-tion shafts, research, testing and demonstration facilities as well as technical facilities. The period between 2000 and 2020 has been a phase of research, development and design focusing on Olkiluoto. Under-ground studies have been carried out in order to obtain the competence necessary for applying for an operating licence. The studies have in-volved determining the geological, rock mechanical, thermal, hydroge-ological and hydrogeochemical properties of the bedrock and examin-ing the excavation damaged zone, among other things. The information has been used in the planning of deposition tunnel and hole placement and as initial data for the safety case.

5.2 CONSTRUCTION STAGE

ONKALO's underground research facility and disposal repository have been designed such that ONKALO can operate as part of the disposal facility when the final disposal of canisters containing spent nuclear fuel begins in approximately 2025. Some of the construction work for the disposal facility has already been completed during the ONKALO construction phase. The work methods and materials used in ONKALO's construction have been selected such that they are acceptable also in terms of the disposal facility.

The encapsulation plant and disposal facility at Olkiluoto include an overground and underground facility section. The underground facility section comprises access routes that extend deep into the bedrock, the tunnels and deposition holes for the placement of the final disposal canisters, and the necessary underground auxiliary facilities and access connections. From the ground surface to the disposal repository, there is a driving tunnel and the necessary number of vertical shafts for ventilation, personnel traffic and canister transfers.

5.3 OPERATING PHASE

Spent nuclear fuel is stored at the interim storages of Fortum's Loviisa nuclear power plant and TVO's Olkiluoto nuclear power plant for at least 20 years before its final disposal. From the interim storages, the spent nuclear fuel is transported to the encapsulation plant and disposal facility at Olkiluoto in transport packaging as special transfers and transports. Transports from Loviisa to Olkiluoto may take place by sea or road. The current plan is to use road transports in the 2040s. The transportation of spent nuclear fuel is subject to strict national and international regulations and agreements. In Finland, spent nuclear fuel transports require a transport licence, which must be applied for from the Radiation and Nuclear Safety Authority (STUK). STUK inspects the transport plan, structure of the transport packaging, qualifications of the transport personnel and arrangements for preparing for accidents and malicious damage. From the Olkiluoto interim storage, spent nuclear fuel is transported to the encapsulation plant as an internal transfer within the nuclear power plant area.

The encapsulation plant is the most important building in the overground facility section. The encapsulation plant is designed such that it can process the spent fuel from the nuclear power plant units of Posiva's owners.Spent nuclear fuel which is brought from the interim storages of nuclear power plants to the encapsulation plant and disposal facility is placed in copper canisters at the encapsulation plant and then transported by a lift or, alternatively, via the driving tunnel into the disposal repository. The disposal repository is located on one level at a depth of approximately 430 metres from the ground surface.

The disposal repository designs are based on the vertical canister deposition solution (KBS-3V). In addition to this, a horizontal deposition solution (KBS-3H) may be applied, in which the canisters are installed in horizontally drilled tunnels.

In the vertical deposition solution, vertical deposition holes are drilled into the floors of deposition tunnels for placement of sealed canisters that withstand corrosion. In both solution alternatives, the space between the canister and bedrock is filled entirely with buffers that surround the canisters and tunnel backfill material.

5.4 CLOSURE PHASE AND RETRIEVABILITY OF THE NUCLEAR FUEL PLACED IN FINAL DISPOSAL

Over the course of the final disposal operations, final disposal sections are closed as canisters are placed in final disposal. When all of the spent nuclear fuel has been placed in final disposal, the encapsulation plant will be dismantled, the tunnels will be backfilled using backfill material, and connections to the ground surface will be closed. Once the licensee with a waste management obligation has acceptably closed the disposal repository and issued a payment to the government for the future monitoring and supervision of the nuclear waste, ownership of and responsibility for the waste is transferred to the government. According to the Nuclear Energy Act, final disposal shall overall be implemented such that post-disposal monitoring is not required in order to ensure safety.

However, it is possible to retrieve to the ground surface the nuclear fuel that has been placed in final disposal in bedrock, provided that sufficient technological and financial resources are available. Retrievability provides future generations with an opportunity to assess the solution in light of their state of knowledge. Retrieval uses the same conventional work technologies and methods as the excavation and construction of the disposal repository. It is possible to retrieve canisters from the disposal repository to the ground surface at all the stages of the project: before the backfilling of the deposition hole, after the deposition hole backfill and before the closure of the deposition tunnel, after the closure of the deposition tunnel and before the closure of all facilities, and after the closure of all facilities. Retrieval is the easiest right before the backfilling of the deposition hole and the most laborious after the closure of all facilities.

6 ENVIRONMENTAL IMPACTS DURING RESEARCH AND CONSTRUCTION AND DURING OPERATING ACTIVITIES

6.1 IMPACTS FROM TRANSPORTS AND TRAFFIC

The traffic to Posiva's encapsulation plant and disposal facility com-prises a small portion of the Olkiluoto Island traffic (some 5% of the overall traffic volume), so it has no major impact on the traffic vol-umes and the impacts caused by traffic.

In addition to the internal transfers at the Olkiluoto nuclear power plant, spent nuclear fuel is transported to the encapsulation plant and disposal facility from the Loviisa nuclear power plant. According to plans, nuclear fuel will be transferred from Loviisa to Olkiluoto either by sea or road. The transports from Loviisa are scheduled to begin in the 2040s.

The number of fuel transports depends on the amount of nuclear fuel, size of the transport packaging and mode of transport. In the different mode of transport alternatives, the environmental impacts resulting from exhaust gas emissions are insignificant due to the small number of transports.

The radiation dose to the population in connection with the transports is considerably lower than the dose incurred from natural background ra-diation in the same period. However, transport container handlers and transport personnel may be exposed to higher levels of radiation during transports compared with exposure to background radiation. Radiation protection has been considered in transport planning, and transports are subject to a separate licence issued by the Radiation and Nuclear Safety Authority.

Radiation doses caused by traffic accidents would be minor. The most severe traffic accidents could result in a radioactive release comprising noble gases and other volatile substances. As a result of a realistic acci-dent scenario, the transports of spent fuel do not cause a significantly elevated health risk to the population resulting from radiation exposure. (*Suolanen et al. 2021*)

6.2 IMPACTS ON LAND USE, CULTURAL HERITAGE, LANDSCAPE, BUILDINGS AND STRUCTURES

The normal operation of the encapsulation plant and disposal facility, anticipated operational occurrences or possible accidents do not limit land use outside of the overground facility area.

In connection with the issuance of the closure permit for the encapsulation plant and disposal facility, land use restrictions may be applied and recorded in the appropriate registers. The limitations may apply to drilling and excavation activities, for example.

The encapsulation plant and disposal facility will have minor impacts on the landscape. The area has no buildings that would have national or local cultural-historical value, significant constructed cultural environments or other such sites. No antiquity sites have been discovered in the Olkiluoto area.

6.3 IMPACTS ON SOIL, BEDROCK AND GROUNDWATER

The surface area required for the underground facility section is approximately 150 hectares for the final disposal of 6,500 tU of fuel. The combined length of the deposition tunnels is approximately 35 km.

The total volume of quarry material corresponding to the amount of fuel to be placed in final disposal is approximately 1,250,000 solid cubic metres. An average of 10,000 solid cubic metres of quarry material will be generated annually during the operating activities. The rock material brought up from the underground disposal repository is stored in a quarry material dumping area at Olkiluoto. This rock material will be primarily used for other applications at Olkiluoto either as filler material as is or as crushed and/or screened rock material. One alternative is to sell the rock material obtained from the tunnel to an external party either as is or crushed.

The residual heat of the spent nuclear fuel will cause the bedrock temperature to rise, resulting in the thermal expansion of the bedrock. For this reason, a slight land upheaval can be observed above the disposal facility during a period of approximately 1,000 years after the beginning of the final disposal of spent nuclear fuel until the residual heat has dissipated.

Groundwater leaks into open tunnels from where it is pumped to the ground surface. This reduces groundwater pressure height around the tunnel system, and high leak volumes may also cause the groundwater level to decrease in the Olkiluoto island area. The volume of leaking water and the extent of its impact are reduced by sealing the rock around the tunnels as work progresses. The impact of ONKALO and the disposal repository on the groundwater level has been assessed by using computational fluid dynamics. The fluid dynamics model is updated regularly, comparing the results to observed values. Both the modelling and the observed results indicate that construction work in the ONKALO area has only caused very minor permanent changes in groundwater level.

Small signs of dilution at the rock surface sections and indications of water being filtered from the Korvensuo basin have been observed in the chemical groundwater composition. The changes observed deep in the bedrock have been minor.

6.4 IMPACT ON AIR QUALITY

Earthworks, work site traffic and separate functions (e.g. rock crushing and quarry material dumping) cause local dusting. Vehicles and machinery generate emissions in the air. These emissions are minor in quantity, and they do not impact air quality outside the area.

6.5 NOISE AND VIBRATION IMPACT

Earthworks, blasting, quarry material processing, crushing and the use of vehicles and machinery generate noise and vibration. The functions that generate vibration and noise are implemented such that they do not cause significant impacts on the environment.

The disposal repository for spent nuclear fuel is constructed as spent nuclear fuel is placed in final disposal. The noise from the excavation of the disposal repository is not heard outside the facility area. During construction, the crushing of the quarry material generates noise in the daytime. The noise area affected by the crushing does not have anything that would be disturbed by the noise. The impacts are not significant due to the short duration of the functions and the small size of the affected area. The crushing of the quarry material will end once all the spent nuclear fuel has been placed in final disposal in the Olkiluoto bedrock. If future excavation methods allow for using mechanical excavation, there is no need to crush the quarry material in the current extent because mechanical excavation generates crushed quarry material.

6.6 IMPACTS ON FLORA, FAUNA AND CONSERVATION AREAS

The project's impacts on the flora and fauna are primarily related to the land areas required for buildings and structures and the related construction work. There are no significant impacts during the operation and after the closure of the disposal repository. Most of the plants take their water from the soil water above the rock surface. Therefore, any reduction of the rock groundwater level caused by the underground facilities will not impact the flora. No significant water level reduction is expected in soil layers.

The impact from final disposal on the Liiklankari Natura area have been studied and assessed in connection with the Olkiluoto partial master planning. The Natura assessment has found that the projects made possible at Olkiluoto through general planning (including the encapsulation plant and disposal facility) do not significantly affect the nature values for which the Liiklankari nature reserve, located on the south coast of Olkiluoto island, has been included in the Natura 2000 conservation programme.

Furthermore, the Liiklankari forest is part of the old forest conservation programme (conserved by decree 3 Dec 1993/1115) and it is a nature reserve of the Finnish government. Nature reserves prohibit actions that may have unfavourable effects on the natural conditions, landscape or preservation of animal or plant species in the area. Based on the Natura assessment for Liiklankari, it can be stated that the project does not cause any significant harm to the conserved natural forest.

Outside the area reserved for the operation of the disposal facility, the utilisation of natural resources, such as picking mushrooms or berries, hunting, fishing and forestry, can be continued as usual.

6.7 IMPACT ON PEOPLE AND ATTITUDES TOWARDS THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL

In the encapsulation of spent nuclear fuel, the releases of radioactive substances from the encapsulation plant and disposal facility are negligible under normal conditions. The amounts of radioactive substances processed at the encapsulation plant at a time are small compared to the corresponding amounts at nuclear power plants.

The analyses evaluating the radiation safety of the encapsulation plant and disposal facility and the radiation doses caused by releases demonstrate that, in normal operation, the annual radiation doses remain negligibly low; the radiation dose incurred by a representative person comprises approximately 0.001% of the 0.01 mSv annual dose limit for normal operations (cf. natural radiation of approximately 5.9 mSv/year). (*Räihä 2021*.)

The attitudes of Finnish people towards nuclear waste have been examined as part of the “Finnish Energy Attitudes” follow-up study. The study has examined and monitored attitudes towards energy political issues for 37 years (1983–2020) already. Previous studies have found that there are clear prejudices towards nuclear waste. In a study conducted in 2020, more than one third (36%) consider that the final disposal of nuclear waste in Finland is safe. The proportion of people with doubts is slightly higher (38%) in the population. Over the course of several decades, trust in safe final disposal has gradually improved. (*Finnish Energy Attitudes 2020.*)

According to a study carried out in 2008 by the Jyväskylä and Tampere Universities (*Litmanen et al. 2010*), one third of the residents of Eurajoki agreed that they receive enough information about final disposal, one third disagreed and one third could not assess the matter. The proportions of residents that trust and do not trust Posiva were equally high (39%). According to the study, 42% of Eurajoki residents are ready to accept the expansion of the disposal facility.

A study conducted in 2007–2008 (Aho 2008) examined how the Eurajoki municipal residents trust the safe final disposal of spent nuclear fuel. According to the responses to the form survey, approximately 40% of the Eurajoki municipal residents had a positive attitude towards the final disposal of spent nuclear fuel, and 12% had a neutral attitude. However, according to the study, 45% of the municipal residents were afraid of the encapsulation plant and disposal facility being located in their home municipality.

In June 2008 a theme interview study (Pöyry Environment Oy 2008) was carried out in order to examine Eurajoki residents’ opinions and attitudes relating to final disposal as well as possible concerns. Most of the interviewees had a neutral or somewhat positive attitude towards the encapsulation plant and disposal facility. Out of the possible final disposal alternatives, deposition in bedrock was considered to be the best. However, there were concerns of safety risks, mainly in the long term. None of the interviewees experienced any actual fear in relation to final disposal, even though they had some concerns e.g. regarding nuclear waste transport risks. The effects of the encapsulation plant and disposal facility on the employment rate and tax revenue were seen as positive things for the municipality. None of the interviewees found that the concerns regarding final disposal would impact their personal life or cause them stress. Only one interviewee thought that final disposal could pose a risk to personal safety.

6.8 IMPACTS ON THE COMMUNITY STRUCTURE, REGIONAL ECONOMY AND IMAGE OF EURAJOKI MUNICIPALITY

The direct employment impact of the construction phase, which began in 2021, is estimated to total approximately 1,700 person-years. During the final disposal operations, i.e. the production phase, the direct employment effects are approximately 130 person-years. The project will have a significant, positive impact on the employment rate of Eurajoki municipality and the region.

According to a 2007 report *"Käytetyn ydinpolttoaineen loppusijoituksen aluetaloudelliset, sosioekonomiset ja kunnallistaloudelliset vaikutukset"* (Regional economical, socio-economic and municipal economical impacts of the final disposal of spent nuclear fuel) (*Laakso et al. 2007*), the decision on the location of the encapsulation plant and disposal facility, Posiva's relocation to Eurajoki, renovation of Vuojoki Manor and renewal of its operation as well as the commencement of the encapsulation plant and disposal facility's research stage and the construction of ONKALO have had a positive effect on the socio-economic, region economical and municipal economical developments in Eurajoki and the entire region in the early 2000s.

The construction and operation of the encapsulation plant and disposal facility will impact the municipal economy of Eurajoki. The real estate tax will lead to the gradual strengthening of the municipal tax revenue as the amount of real estate tax grows over the course of the construction. This allows for the municipality to have a strong annual margin compared to other municipalities and provides exceptional leeway, which will make the municipality increasingly attractive for potential movers in relation to the other municipalities in the region.

According to the study by Laakso, in the municipalities of the region there is satisfaction with the positive region economical impacts of the project. One aspect particularly considered to be favourable is that the construction and operation of the facility are long-term activities with relatively foreseeable effects that are distributed over a long period. The potential negative external effects that were earlier associated with the encapsulation plant and disposal facility have not materialised. Based on the available information, the facility project has not disturbed the residents or companies, and the awareness of and image of Eurajoki municipality have strengthened.

7 IMPACTS OF OPERATIONAL OCCURRENCES AND ACCIDENTS

The encapsulation plant and disposal facility handles small amounts of cooled spent fuel at a time, so the radiation dose in a rare disruption or accident situation would therefore be very small.

In order to analyse the consequences of a potential release of radioactivity in exceptional circumstances, there are anticipated operational occurrences and postulated accidents determined for the encapsulation plant and disposal facility. Operational occurrences differ from accidents such that the consequences from operational occurrences are not as severe as in accidents but operational occurrences can occur more often. Typical operational occurrences are equipment failures or malfunctions that can result in the release of radioactivity from systems that contain it. Typical accidents are falls of heavy loads in which the nuclear fuel being handled may become damaged.

The design of the encapsulation plant and disposal facility must also take into account the impacts resulting from natural phenomena and other events external to the plant that are considered to be possible. Such natural phenomena include lightning strikes, earthquakes and floods. Other events external to the plant to be considered include electromagnetic disturbances, airplane crash, wildfire and explosion. These threat scenarios shall be considered in the design of the encapsulation plant and disposal facility to the sufficient extent.

The structures of the encapsulation plant and disposal facility shall be implemented such that even potential accidents at the different stages of handling the nuclear fuel that lead to the damaging of the nuclear fuel will not pose an immediate health hazard to the personnel or the residents of the surrounding areas. In case of an operational occurrence, radioactivity may be released into limited facilities at the encapsulation plant, from where the release is filtered and conveyed outside via the ventilation system. In the disposal repository, operational occurrences and accidents that involve a release of radioactive substances are highly unlikely.

Based on the conducted analyses, it can be stated that the radiation doses do not exceed the specified radiation dose limits in any discussed scenario:

- in normal operation, the annual radiation doses incurred by the surrounding population remain negligibly low; the radiation dose incurred by a representative person comprises approximately 0.001% of the annual dose limit for normal operations (0.01 mSv).
- in operational occurrences, the doses are, similarly, negligible; the radiation dose incurred by a representative person comprises approximately 0.002% of the annual dose limit (0.1 mSv).
- in class 1 postulated accidents, the doses remain at 0.0004 mSv (0.04% of the limit of 1 mSv)
- in class 2 postulated accidents, the doses remain at 0.17 mSv (3.4% of the limit of 5 mSv) and in a scenario analysed for sensitivity analysis at 2.3 mSv (46% of the limit of 5 mSv)
- in postulated accident extension scenarios, the doses remain at 2.1 mSv (10.5% of the limit of 20 mSv).

Based on the analyses, it can be stated that the normal operation of the encapsulation plant and disposal facility or their operational occurrences and accidents will not cause danger to the personnel or the surrounding population. The highest dose will be incurred immediately adjacent to the facility area assuming that this location is used for permanent residence and agriculture and home-grown products are the primary source of nutrition. Most of the dose comes via food chains from radionuclides that settle on the ground, similarly as in connection with operational occurrences.

The significance of the external radiation dose from fallout increases as the observation period lengthens. External exposure accounts for the majority of a dose accumulated over the course of 50 years. Annual dose levels remain so low that there is no risk of immediate health effects. Similarly, based on population doses, the risk of stochastic effects remains very low.

8 LONG-TERM SAFETY

The mechanically strong and corrosion resistant canisters will be placed in stable bedrock at a depth of approximately 430 metres and surrounded by bentonite clay. It is very likely that they will contain all the radioactive materials inside them for at least a million years. However, the possibility of individual canisters becoming damaged during this time cannot be entirely excluded. In such cases, radioactive substances could be slowly released into the environment. Canister leaks could be the result of an already damaged canister ending up in the disposal repository, a few canisters placed in unfavourable positions becoming damaged in strong earthquakes that could occur during an ice age at ice retraction phases, and very dilute groundwater eroding the bentonite clay from around a canister and causing the corrosion of the canister.

However, even in a worst case scenario, the number of canister failures expected in the next hundreds of thousands of years is so little that the resulting releases of radioactive isotopes would only have a very low impact on people and the rest of the surrounding living nature. The safety assessments have also taken into account the uncertainties affecting the release of radioactive substances and their travel. The feasibility as well as sufficient quality and safety of technical solutions will be demonstrated by tests. The full-scale safety case that supports the operating licence application of the disposal repository is based on these tests and their results. The meeting of the requirements is examined in the safety case prepared for the operating licence application in accordance with Guide YVL D.5 (SC-OLA). It finds that the annual radiation doses resulting from developments that are considered likely will remain clearly below the limit provided in Guide YVL D.5 over the course of the next 10,000 years, even for the most exposed people, and the doses incurred by other people will remain negligible. It is estimated that, after this time, the releases of radioactive substances resulting from developments that are considered likely will, at most, remain under one-thousandth of the maximum values specified by STUK. Furthermore, the radiation exposure of the fauna will remain clearly under the reference value proposed in international projects. The resulting radiation doses and release rates of radioactive substances have been assessed taking into account the possible random deviations from the operability requirements for the final disposal system as well as the uncertainties in the calculation models and initial data used in the assessment.

The conclusions presented above are justified in detail in the safety case documentation to be submitted to STUK and in Chapter 8 of this report.

9 FOLLOW-UP OF ENVIRONMENTAL IMPACTS

Posiva is following up on the environmental impacts from the final disposal project as part of the Olkiluoto Monitoring Programme (OMO) *(Posiva 2021a)*, whose design takes into account the possible impacts on the environment that have been identified in this and previous impact assessments.

The follow-up of environmental impacts aims at:

- producing information on the project's environmental impacts
- determining which changes result from project implementation
- determining the degree to which the impact assessment results correspond to reality
- determining how the mitigation of harm has succeeded
- initiating any necessary measures in case unforeseen significant harm occurs.

In the monitoring programme, the monitoring of environmental impacts is carried out mainly through the monitoring of the surface environment sub-area, in addition to which the groundwater conditions are monitored as part of both the hydrogeochemistry and the hydrology and hydrogeology sub-areas.

The monitoring programme includes tracking non-radiation items, such as noise, flora, fauna, surface water and groundwater. Observations made by this time and assessments of impacts during final disposal have been presented above.

The impacts of final disposal operations on the environment's radiation levels and radionuclide concentrations are tracked at Olkiluoto as part of the environmental radiation monitoring programme. The tracking of radiation impacts is based on measurements of radioactive substance releases and concentrations as well as radiation dose rate measurements. Concentrations and dose rates are also assessed through calculations based on release and weather data, among others, because it is expected that radioactive substances originating from the facility cannot be observed in the environment due to their low quantity. The expected radiation impacts are so low that no particular population health tracking is considered necessary: it would not be possible to detect any health detriments from normal morbidity (Smith 2016). If necessary, it is, however, possible to compare the health of the surrounding population to the population living further from the site by using the data maintained by the National Institute of Public Health, for example.

The monitoring of radioactive substance concentrations and radiation dose rate was started already before the final disposal operations for the purpose of the baseline report for radioactivity in the environment in order to obtain reference data for different directions and distances. Concentrations are measured from air, water, soil, organisms, agricultural products, products gathered in the wild, and game. Weather data and other data necessary for assessing the calculated impacts will also be collected, as is currently being done.

Releases of radioactive substances into the environment will be measured at the final disposal stage. Typical measurement locations are the exhaust air and waste water outlets. The concentration and dose rate measurements that have been started will be continued.

After closure, environmental impact follow-up can include radioactivity measurements from the ground surface and deep drill holes. The holes will also allow for monitoring groundwater level, flows, chemistry, temperature, etc. On the ground surface, geophysical measurements can be used for tracking the occurrence of micro earthquakes. Compromising the integrity of nuclear material by illegal means would require activity that is visible on the ground surface. This activity could be detected and monitored internationally via satellites, for example.

GLOSSARY

Driving tunnel
A driving ramp leading from the ground surface to the final disposal level at a slope of 1:10. Main access route to the underground research facility ONKALO.

Radioactivity
Radioactivity indicates the number of radioactive decays that occur in a radioactive substance within a specific time period. The unit for radioactivity is Becquerel (Bq), indicating one decay per second.

Dose rate
The dose rate indicates the size of the radiation dose a person incurs within a specific time period.

Local detailed plan
In accordance with the Land Use and Building Act, a local detailed plan provides detailed regulations on organising the use of a land area.

Bentonite
A type of natural clay generated through the transformation of volcanic ash. A special characteristic of bentonite clay is that it expands as a result of water absorption. According to the plans, bentonite will be used as a buffer material between a canister and bedrock and as one of the backfill materials for the disposal repository.

Becquerel (Bq)
The unit for radioactivity, which indicates one radioactive decay per second. The radioactive substance concentrations of foods are specified as Becquerels per unit of weight or volume (Bq/kg or Bq/l).

Biosphere
The part of the Earth's surface where life is possible. Used in the final disposal site research and safety assessment (as opposed to the bedrock), and it includes the living nature, soil and the groundwater, bodies of water and atmosphere.

BWR
Boiling Water Reactor. Olkiluoto 1 and Olkiluoto 2 are boiling water reactors.

Decibel (dB)
Unit of sound pressure level. An increase of 10 dB in the noise level means that the energy of the sound grows tenfold. Environmental noise measurements typically use A-weighted decibels, dB(A), which emphasises the frequencies of sound that the human ear is the most sensitive to.

Diffusion
A phenomenon in which molecules strive to move from a high concentration to a lower concentration, evening out any differences in concentration over time.

Effective dose
The weighted sum of the equivalent doses of tissues and organs exposed to radiation. The unit of effective dose is sievert (Sv).

Equivalent dose
The equivalent dose is the product of the absorbed dose and the radiation quality factor. Its unit is sievert (Sv). Equivalent doses allow for comparing the radiation doses caused by different types of ionising radiation.

EPR
EPR (European Pressurised Water Reactor) is an advanced version of the third-generation pressurised water reactor in which special attention has been paid particularly to safety aspects. The Olkiluoto 3 nuclear power plant unit is an EPR type pressurised water reactor.

EURATOM
The European Atomic Energy Community of the European Union. Finland is a member of EURATOM.

Gray (Gy)
The unit of absorbed dose, which indicates how much energy ionising radiation deposits in a mass of material. 1 Gy = 1 joule/kg Its submultiples are mGy = 1/1,000 gray and μGy = 1/1,000,000 gray.

Hydrogeochemical model
A modelled description of the chemical properties of groundwater and the processes that affect them.

Hydrogeological model
A modelled description of the physical properties of groundwater, the conditions and flow.

IAEA
International Atomic Energy Agency.

ICRP
International Commission on Radiological Protection.

Ionisation
A change in the electron structure of an atom that can cause changes in molecules, including DNA.

Ionising radiation
Short-wavelength electromagnetic radiation and particle radiation that cause ionisation either directly or indirectly.

Reprocessing
The separation of useful nuclides from spent nuclear fuel. The fission products and some transuranium elements remain.

Canister
An engineered release barrier comprising a copper shell, base and lids and a cast-iron insert for the final disposal of spent fuel elements.

KBS-3
A principle solution for final disposal developed by SKB, the company responsible for Swedish nuclear waste management. “KBS” refers to “KärnBränsleSäkerhet” (nuclear fuel safety).

KBS-3H
A principle solution for final disposal based on the multi-barrier principle. The first release barrier, the canister, is placed in the bedrock in a horizontal position (H = horizontal).

KBS-3V
A principle solution for final disposal based on the multi-barrier principle. The first release barrier, the canister, is placed in the bedrock in a vertical position (V = vertical). According to Posiva’s current plans, the final disposal canisters will be placed in vertical holes drilled in deposition tunnels.

kgU
Kilograms of uranium. Refers to the amount of uranium in fresh nuclear fuel. In spent nuclear fuel, 95–96% of this uranium content remains. The rest has been converted into fission products, plutonium and other transuranium elements.

Collective effective dose
The effective total radiation dose incurred by a specific population. Its unit is mansievert (manSv).

KPA storage
The spent nuclear fuel interim storage.

KTM
The Ministry of Trade and Industry, whose duties were assigned to the Ministry of Economic Affairs and Employment (TEM) as of 1 January 2008.

Transport container
A special container with radiation shielding intended for transports and short-term storage of spent nuclear fuel. In addition to radiation shielding, the container provides mechanical and thermal protection during the transport, handling and storage of spent fuel. Can also be referred to as “transfer cask”.

Spent nuclear fuel
Nuclear fuel is referred to as “spent fuel” after it is removed from the reactor. Spent nuclear fuel radiates strongly.

Natural background radiation
Radiation from natural radioactive substances and space.

Mansievert (manSv)
The unit of collective dose. For example, if, in a population of 1,000 people, each person incurs an average radiation dose of 20 millisievert, the collective dose is 1,000 X 0.02 Sv = 20 manSv.

Multi-barrier principle
Implementing final disposal such that radionuclides must penetrate multiple consecutive and independent barriers before they can become released into the living environment.

Megawatt (MW)
Unit of power (1 MW = 1,000 kW).

Natura 2000
A network of nature conservation areas according to the EU Nature Directive, which aims at protecting particularly European natural environments, animals and plants that are endangered, rare or characteristic.

Nuclide
A nuclide is an atomic nucleus with a specific number of protons (Z) and neutrons (N).

Olkiluoto encapsulation plant and disposal facility
A nuclear facility complex that comprises two nuclear waste facilities: an encapsulation plant located on the surface and a disposal facility excavated in the bedrock. The disposal facility also includes overground buildings that serve it. In the encapsulation plant, the spent nuclear fuel is placed in a final disposal canister and the canister is closed. The encapsulated spent nuclear fuel is placed in final disposal in the disposal facility.

ONKALO
The term originally referred to the underground bedrock research facility of the spent nuclear fuel disposal facility, but now ONKALO refers to the entire disposal repository.

Burn-up
Burn-up indicates how much thermal energy fuel has generated per one kg of uranium. The unit for burn-up is MWd/kgU (megawatt-day per kg of uranium).

Fuel element
Fuel element refers to a unit of nuclear fuel assigned to Posiva for final disposal. A fuel element may be a fuel assembly and a channel (BWR, VVER), a fuel assembly (PWR) or a BWR fuel assembly without a channel. A fuel assembly comprises fuel rods that contain the uranium used as nuclear fuel. The fuel rods are held together by spacers and end pieces. In some fuel types, the assembly is surrounded by a metallic case which is called the flow channel (or in the case of VVER fuel, the protective case).

Posiva’s encapsulation plant and disposal facility
Posiva’s nuclear facility complex which includes the encapsulation plant and disposal facility as well as the other structures necessary for their operation.

PWR
Pressurised Water Reactor. Olkiluoto 3 is a PWR type plant unit even though its commercial name is EPR.

Radioactive
A radioactive substance contains atomic nuclei which can become other nuclei as a result of conversion or decay. In connection with the decay process, ionising radiation (e.g. alpha, beta and gamma radiation) is usually generated. See “Radioactivity”.

Radioactivity
The ability of an atomic nucleus (nuclide) to transform into a different nucleus (nuclide). A radioactive nucleus can emit an alpha or beta particle to transform into another nucleus which, in turn, may emit electromagnetic radiation. This transformation is called radioactive decay. Each atomic nucleus (nuclide) has an inherent decay constant (half-life).

Radionuclide
A radioactive nuclide. See “Nuclide”.

Radon Rn-222.
A radioactive gas with no stable isotopes. The Rn-222 generated as a decay product of uranium in the bedrock causes most of the natural radiation exposure in Finland.

The Richter scale
A mathematical logarithmic scale for measuring the strength (magnitude) of earthquakes.

Sievert (Sv)
The unit of equivalent dose and effective dose. Used for describing the statistical harmful effects of human radiation exposure (radiation dose). A sievert is a very large unit. Therefore, millisievert (mSv) or microsievert (μSv) is usually used when describing doses. One sievert equals 1,000 millisievert and 1,000,000 microsievert.

SR-Site
A safety assessment published in 2011 by SKB, the company responsible for Swedish nuclear waste management. The assessment focuses on the KBS-3V final disposal solution in Forsmark. Most of the safety assessment will eventually also be applicable to the Olkiluoto disposal repository as the technical solution and the primary characteristics of the final disposal site are similar.

STUK
Radiation and Nuclear Safety Authority.

Radiation dose
The radiation dose describes the harmful effects of human radiation exposure. The unit for the radiation dose is sievert (Sv). Radiation dose is often referred to as “dose”.

TEM
The Ministry of Economic Affairs and Employment, which took over the duties of the Ministry of Trade and Industry (KTM) as of 1 January 2008.

tU
Tonnes of uranium.

Uranium
An element with the chemical symbol U. Uranium accounts for 0.0004% of all the materials in the Earth’s crust (4 g per one tonne). All isotopes of uranium are radioactive. The most common isotope of natural uranium is U-238, which has a half-life of 4.5 billion years. Uranium-235, which can be used as fuel at nuclear power plants, accounts for 0.71% of the total mass of natural uranium. Uranium-235 has a half-life of 700 million years.

Release barrier
The purpose of release barriers is to prevent the travel of radionuclides in the final disposal system. Release barriers include the canister, bentonite buffer and bedrock, for example. Release barriers can also be referred to as “emission barriers”.

VLJ cave
The low and intermediate level operating waste repository.

VTT
VTT Technical Research Centre of Finland

VVER-440
The reactor type used at Loviisa 1 and Loviisa 2 (pressurised water reactor).

Enrichment level
The uranium isotope U-235’s proportion to the total uranium quantity. There is 0.72% of isotope U-235 in natural uranium. Light water reactors use fuel with an enrichment level of 3–4%.

EIA
Environmental impact assessment. A procedure according to the EIA act, or “EIA procedure”.

YVL Guide
YVL Guides are regulatory guides issued by the Radiation and Nuclear Safety Authority, which describe the requirement level of radiation and nuclear safety supervision. The safety requirements for the use of nuclear energy are described in the YVL Guides.

1 BACKGROUND AND PURPOSE OF THE REPORT

1.1 CURRENT DECISIONS AND PRACTICES

In 1997–1999, Posiva Oy (Posiva) carried out an EIA procedure for the final disposal of spent nuclear fuel. At the time, the procedure covered the amount of spent nuclear fuel generated by six nuclear power plant units: a total of 9,000 tonnes of uranium (tU).

In its decision-in-principle application submitted to the Government in 1999, Posiva presented that the spent nuclear fuel from the operating Olkiluoto and Loviisa nuclear power plants would be placed in final disposal in the bedrock of Olkiluoto, Eurajoki by using the KBS-3 concept.

The Government made a favourable decision-in-principle on the matter in December 2000, and it was ratified by the Finnish Parliament in May 2001. According to the decision-in-principle, the maximum amount of spent nuclear fuel that can be processed at the encapsulation plant and disposal facility and placed in final disposal shall be equivalent to 4,000 tU. A favourable decision-in-principle on the fifth nuclear power plant unit to be constructed in Finland (Olkiluoto 3) was made in 2002. In connection with this, based on Posiva's earlier application, a decision-in-principle was made on the construction of the spent nuclear fuel disposal facility with an extension such that the spent nuclear fuel from Olkiluoto 3 can also be placed in final disposal there. This decision in principle would allow the construction of a disposal repository for a maximum of 2,500 tU. Therefore, based on the 2000 and 2002 decisions-in-principle,

the maximum amount of spent nuclear fuel that can be processed and placed in final disposal at the Olkiluoto encapsulation plant and disposal facility is 6,500 tU.

In early 2008, Posiva prepared an updated report on the disposal facility's environmental impacts. The EIA that was completed previously already covered the amount of spent nuclear fuel for the sixth nuclear power plant, but the coordinating authority found that the information in the EIA report should be updated. The updated report was included as an appendix in the decision-in-principle application concerning the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit.

In 2008–2009, Posiva also carried out a completely new EIA procedure in order to increase the capacity of the disposal repository by 3,000 tU. The new Environmental Impact Assessment report was included as an appendix in the decision-in-principle application concerning the final disposal of spent nuclear fuel from the Loviisa 3 plant unit.

In connection with the decision-in-principle application concerning the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit, an application concerning the final disposal of spent nuclear fuel from the Loviisa 3 plant unit was being processed. On 21 April 2010, the Government made a favourable decision-in-principle concerning the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit at Olkiluoto. The Finnish Parliament ratified the decision on 1 July 2010. Regarding the construction project for the Loviisa 3 plant unit and the final disposal of its spent nuclear fuel, the Government found in its decisions-in-principle issued on 6 May 2010 that the construction of the Loviisa 3 plant unit and the construction of the nuclear fuel disposal facility at Olkiluoto with an extension such that the facility would allow the processing and final disposal of the spent nuclear fuel generated during the operation of Loviisa 3 are not in the overall interest of society. On the basis of the decisions-in-principle issued by the Finnish Government, no more than 9,000 tU of spent nuclear fuel can be placed in final disposal at Olkiluoto.

Later, in 2015, the decision-in-principle concerning the Olkiluoto 4 plant unit expired due to the termination of the project. In connection with this, Posiva's decision-in-principle for the final disposal of spent nuclear fuel from the Olkiluoto 4 plant unit expired. Therefore, in November 2015, Posiva was issued a construction licence for the final disposal of 6,500 tU of spent nuclear fuel.

Posiva is now applying for an operating licence for this amount.

The operating licences of the nuclear power plant units located at Olkiluoto (OL1, OL2 and OL3) take into account the processing and storage of operating waste generated at Posiva's nuclear facilities. The final disposal of Posiva's operating waste has also been taken into account in the licencing for the near-surface final disposal planned at Olkiluoto and the modification of the operating licence conditions for the VLJ cave, which are scheduled to be completed in the first half of the 2020s. Posiva assigns the waste management obligation concerning its operating waste to TVO and TVO shall manage Posiva's operating waste according to its established practices.

1.2 PURPOSE OF THE REPORT

The operation of the spent nuclear fuel encapsulation plant and disposal facility is subject to an operating licence issued by the Finnish Government. This report is an up-to-date account of the environmental impacts from final disposal operations, and it is included as an appendix to the operating licence application submitted to the Government. The account is based on 6,500 tU of spent nuclear fuel and on the level of knowledge in 2021 concerning the final disposal operations and their environmental impacts. The previous update of the environmental impact assessment report was submitted to the Finnish Government as part of Posiva's construction licence application.

2 FINAL DISPOSAL PROJECT

2.1 ALTERNATIVES FOR ACTIONS AFTER INTERIM STORAGE

2.1.1 BACKGROUND FOR THE CURRENT ALTERNATIVE IN FINLAND

In order to protect people and the environment, spent nuclear fuel must be kept isolated from nature. The current interim storages meet this requirement. The safe operation of the storages can continue for decades with the appropriate service and maintenance measures. However, the interim storages are not a solution intended to be final. The objective is to find a permanent solution for the management of spent nuclear fuel.

One alternative presented earlier was the reprocessing of nuclear fuel. In reprocessing, the uranium remaining in the spent nuclear fuel is separated for reuse from the generated plutonium. According to the plans, reuse would take place in the same or similar reactors or, at a later stage, in fast-breeder reactors. However, reprocessing generates nuclear waste that requires waste management.

In connection with the Loviisa power plant contract, it was agreed, at the initiative of the Soviet Union, that the spent nuclear fuel from the Loviisa reactors would be returned to the Soviet Union (Russia). The aim of the Soviet Union was to reuse the useful substances contained in the spent nuclear fuel.

Similarly, the reprocessing options for the spent nuclear fuel from the Olkiluoto reactors were explored, and reprocessing contracts were negotiated with foreign companies. However, the availability of reprocessing capacity was low and the prices asked for the services were high. Moreover, the contracts required that the nuclear waste generated during reprocessing would have to be returned to Finland. As the price of uranium started to decrease in early 1980s and there were no guarantees for the utilisation of the uranium or plutonium separated in reprocessing, no reprocessing contracts were made. Due to the low requirement, constructing a reprocessing facility in Finland was never even considered.

In 1994, the Nuclear Energy Act was changed such that nuclear waste could no longer be imported to Finland or exported from Finland. The returns of nuclear fuel from Loviisa stopped in 1996 as a result of the import and export prohibition for nuclear waste. Due to the legislative change, Finland decided on developing a final disposal solution for spent nuclear fuel.

2.1.2 DIRECT FINAL DISPOSAL

Posiva's final disposal plans are based on the KBS-3 concept, which has been developed by Svensk Kärnbränslehantering AB (SKB), the company responsible for Swedish nuclear waste management. The implementation is based on the multi-barrier principle. The radioactive substances are contained inside multiple redundant release barriers such that the failure of one barrier or a foreseeable geological or other change does not compromise the operability of the isolation. The solution does not require care or supervision from future generations.

The final disposal canisters will be placed in vertical holes drilled in deposition tunnels (KBS-3V). However, Posiva has also agreed with SKB on continuing the development of the horizontal deposition alternative (KBS-3H) as well as its safety and feasibility assessment alongside the vertical deposition solution.

2.2 DESCRIPTION OF THE FINAL DISPOSAL SOLUTION

Posiva is applying for an operating licence for operating a spent nuclear fuel encapsulation plant and disposal facility at Olkiluoto. The purpose is to place the spent nuclear fuel accumulated at TVO's nuclear power plants at Olkiluoto and Fortum's nuclear power plants in Loviisa in the disposal facility; this disposal is intended to be permanent. Posiva's responsibilities include the final disposal of spent nuclear fuel generated by its owners' nuclear power plants and other nuclear waste management expert duties.

An underground research facility (ONKALO) has been built in the Olkiluoto final disposal area for researching the final disposal of spent nuclear fuel. ONKALO has been used for collecting the necessary additional information for the construction licence application for the disposal facility. Research methods relating to geology, hydrology, geochemistry and geophysics are applied in order to study the bedrock. In addition to bedrock studies, ONKALO provides the opportunity to develop bedrock construction and final disposal technology under actual conditions. The bedrock facilities of ONKALO are connected to be part of the disposal facility.

2.3 LOCATION AND LAND USE REQUIREMENT OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

Posiva's disposal facility area is located on the island of Olkiluoto in Eurajoki municipality, on the Finnish west coast (Figure 2-1). The straight-line distance from Olkiluoto to the nearest city, Rauma, is some 13 km, with a driving distance of some 25 km. The driving dis-tance from Pori to

Figure 2-1. Locations of Eurajoki and Olkiluoto. Eurajoki is located along national road 8.

Olkiluoto is approximately 54 km. From national road 8, the distance to the disposal facility area is approximately 14 km.

Of Finland's neighbouring countries, the nearest to the disposal facility is Sweden, whose closest continental areas are located some 200 km west from the Olkiluoto encapsulation plant and disposal facility.

The spent nuclear fuel disposal facility area is located in the centre part of the Olkiluoto island

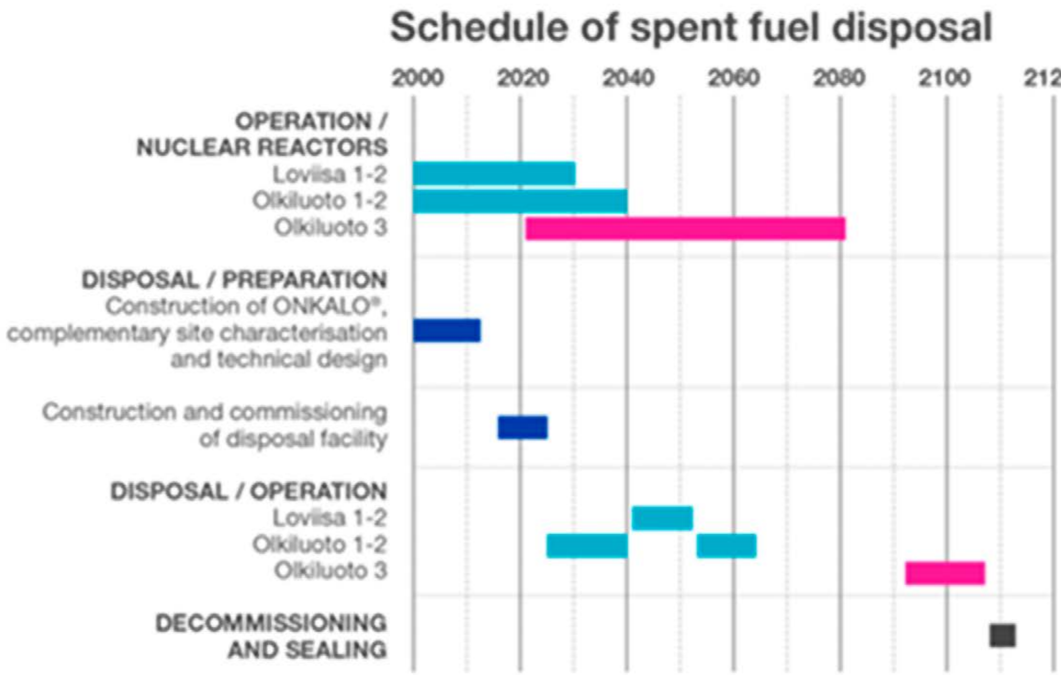


Figure 2-2. The planned operating times of TVO's nuclear power plant units at Olkiluoto and Fortum's nuclear power plant units in Loviisa and the schedule for the final disposal of their spent nuclear fuel.

(Figure 6-3). The overground construction area of the disposal facility area, i.e. the floor area of buildings, roads, warehouses and fields, totals approximately 20 hectares. The surface area required for the underground facility section is approximately 150 hectares for the final disposal of 6,500 tU of fuel.

2.4 PROJECT SCHEDULE

The encapsulation plant and disposal facility will be constructed be-tween 2016 and 2024 such that the final disposal of spent nuclear fuel is started approximately in 2025. According to the current plans, the final disposal would end approximately in 2110. However, the end time is subject to several future decisions.

The aspect that affects the final disposal schedule the most is the long cooling time for nuclear fuel. The nuclear fuel used at the Olkiluoto 1 and 2 and Loviisa 1 and 2 plant units requires approximately 40 years of cooling and the nuclear fuel used at the Olkiluoto 3 plant unit re-quires approximately 60 years of cooling before final disposal. At a minimum, nuclear fuel must cool for approximately 20 years before it is placed in final disposal. The figure (Figure 2-2) presents the timeta-ble for final disposal with the planned final disposal schedules of the spent nuclear fuel from the operating plant units.

2.5 CONNECTIONS TO OTHER PROJECTS, PLANS AND PROGRAMMES

2.5.1 TVO'S OLKILUOTO NUCLEAR POWER PLANT

The largest electricity generation complex in Finland operates on Olkiluoto Island. At Olkiluoto, TVO has two boiling water reactors, each of which has a nominal electric power of 890 MWe (net). The Olkiluoto 1 plant unit was connected to the national grid for the first time in September 1978, and the Olkiluoto 2 plant unit was connected in February 1980. Furthermore, the Olkiluoto 3 plant unit, a pressurised water reactor with a nominal electric power of approximately 1,600 MWe (net), will be connected to the national grid in 2022. After the 2021 annual outages, the Olkiluoto power plant had in storage a total of 9,728 spent nuclear fuel elements, containing approximately 1,630 tonnes of uranium (tU). The figure (Figure 2-2) shows the planned operating life of the Olkiluoto nuclear power plant units.

2.5.2 FORTUM'S LOVIISA NUCLEAR POWER PLANT

Fortum's Loviisa nuclear power plant units LO1 and LO2 are located on Hästholmen island in Loviisa, some 80 km east of Helsinki. At the Loviisa power plant, there are two pressurised water reactors, each of which has a nominal electric power of 496 MWe (net). Commercial operation started in May 1977 for LO1 and in January 1981 for LO2. After the 2021 annual outages, the Loviisa power plant had in storage a total of 6,807 spent nuclear fuel elements, which is equivalent to approximately 794 tonnes of uranium. The figure (Figure 2-2) shows the planned operating life of the Loviisa nuclear power plant units.

2.6 LIMITATION OF THE ENVIRONMENTAL IMPACT ASSESSMENT

The environmental impacts have been assessed for the entire scope of the encapsulation plant and disposal facility. This report presents the environmental impacts of the final disposal project in a situation where 6,500 tonnes of uranium of spent nuclear fuel would be placed in the disposal facility. The final disposal operations are scheduled to start in approximately 2025. According to the current plans, the final disposal of spent nuclear fuel will end in approximately 2120.

The assessment takes into account the long-term safety of the disposal facility, i.e. the time after the closure. In terms of long-term safety, the review period extends to hundreds of thousands and even millions of years. The behaviour of the final disposal system has been described and analysed starting from the deposition of the first canisters until a very distant future, up to approximately one million years.

This report primarily presents the environmental impacts from the activities that take place in the facility area as well as the transports of spent nuclear fuel. The combined effects from the current activities at Olkiluoto and the planned future activities are reviewed as part of the environmental impact assessment. Furthermore, it has been assessed whether the project will have impacts that extend outside the Finnish national boundaries. The previous update of the environmental impact assessment report was submitted to the Finnish Government as part of Posiva's construction licence application.

Here, "review area" refers to the area defined for each impact type in which the environmental impact in question is determined and assessed. The extent of the review area depends on the environmental impact being examined. "Impact area" refers to an area in which the environmental impact is estimated to occur based on the report.

Posiva's nuclear facilities have a very long operating life (approximately 100 years) and they will be serviced and modernised during this time. However, due to the simple principles behind the facilities, the impacts on the environment are minimal, and it is considered that the facilities will only undergo a few modernisations over the course of their operating life. Modernisations and servicing will be scheduled in connection with changing the nuclear fuel type used; at this time, safety system improvements that are considered necessary are also carried out.

Posiva has in place a monitoring programme for tracking the environmental impacts. This programme is assessed regularly in order to ensure that the relevant parameters are being tracked. Posiva will continue the environmental monitoring throughout the facilities' operating life and will transfer its data to the authorities after the nuclear facilities have been closed and the Government takes over the responsibility for the supervision.

3 DESCRIPTION OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

3.1 OVERVIEW OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY

Posiva's final disposal solution is based on a principle solution known as KBS-3, which has been developed by Svensk Kärnbränslehantering AB (SKB), the company responsible for Swedish nuclear waste man-agement. The development of the solution was started already in the 1970s, and the KBS-3 solution was reported in 1983. After this, Posiva has participated in the collaboration for the further development of SKB's KBS-3 solution. In the 2010s and 2020s, Posiva's development efforts have focused on the development of industrial solutions that en-sure the same safety level as previous solutions.

The purpose of the Olkiluoto encapsulation plant and disposal facility is packing (encapsulating) the spent nuclear fuel elements

- accumulated in the nuclear power plants of Posiva's owners in a form required for permanent deposition in bedrock and
- their deposition in the Finnish bedrock in a manner intended to be permanent.

The Olkiluoto encapsulation plant and disposal facility comprises two parts (Figure 3-1):

- an overground encapsulation plant where the spent nuclear fuel delivered from the Loviisa and Olkiluoto nuclear power plants is received and packed in final disposal canisters, and
- an underground disposal facility where the encapsulated spent nuclear fuel is placed in final disposal.

On the ground surface, in addition to the actual encapsulation plant, there are facilities for auxiliary and ancillary functions, including shaft buildings; office and laboratory facilities; warehouse and workshop facilities; and facilities required by HPAC, automation and electrical systems. A separate area is reserved for storing the quarry material and crushed rock. The bentonite blocks and granular material are manufactured from bentonite powder, and they will act as an insulation material for deposition holes. From the ground surface, there is one driving tunnel, four vertical shafts, two ventilation shafts as well as personnel and canister shafts leading to the underground disposal repository. The final disposal canisters are transported to the deposition depth by using a canister lift. The construction area of the facility area, i.e. the floor area of buildings, roads, warehouses and fields, totals approximately 20 hectares (Figure 3-2).

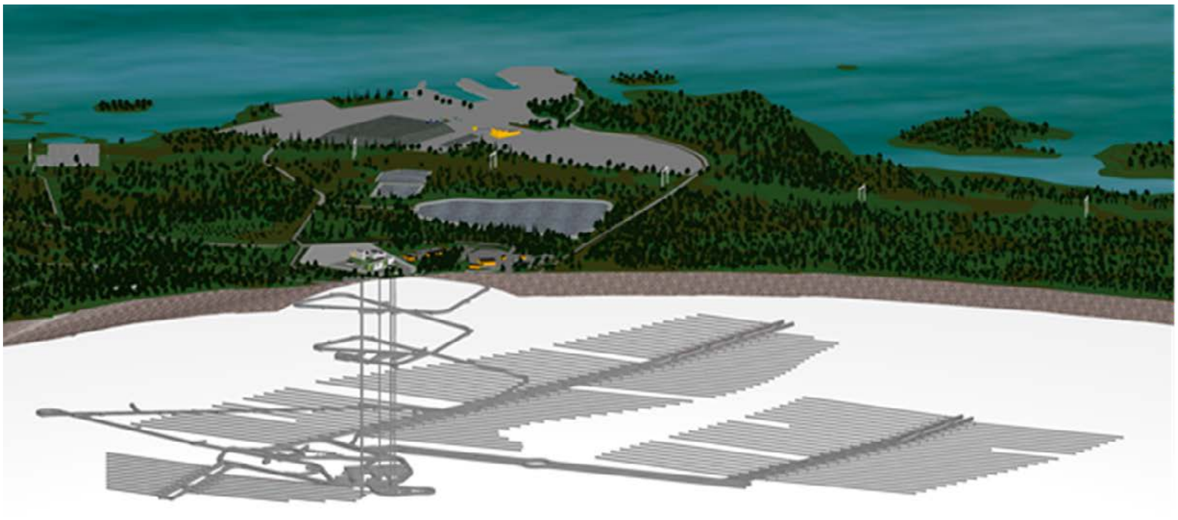


Figure 3-1. An over/underground visualisation of the Posiva facility area

■ **Figure** 3-2. Posiva's overground facility area.

The underground disposal facility is divided into two sections:

- the disposal repository where the canisters that contain spent nuclear fuel are placed and
- other underground facilities, which include the central tunnels connecting deposition tunnels as well as technical facilities and vertical shafts.

3.2 THE DESIGN BASES FOR FINAL DISPOSAL

The long-term safety concept of the final disposal solution is based on the multi-barrier principle, i.e. several redundant release barriers, such that the reduced performance of any single release barrier does not compromise long-term safety. The engineered release barriers include the canisters, the surrounding clay buffer that protects them from bedrock movements and potentially harmful substances in groundwater, and the deposition tunnel backfill material, which supports both the buffer and the rock. Furthermore, the buffer and deposition tunnel backfilling restrict the flow of groundwater in canister surroundings. The release barriers also include other components, such as the backfilling of other facilities as well as the plugs and closures of deposition tunnels, central tunnels, shafts, driving tunnels and research holes. They are designed to be compatible with the canister, buffer, deposition tunnel backfilling material and bedrock and to support the safety functions of these. The release barrier nearest to the spent nuclear fuel, i.e. the canister, is placed in a vertical hole drilled into intact bedrock. This is called the KBS-3V solution. In addition to the redundant release barriers, the release of radionuclides is significantly slowed down by the structure of the spent nuclear fuel; in the conditions deep in the bedrock, uranium dissolves into water very slowly. The multi-barrier principle for final disposal is shown in the below figure (Figure 3-3).

The gas- and water-tight canister contains the spent nuclear fuel and its radioactive substances. The massive final disposal canisters have a spheroidal graphite cast iron insert and a copper outer shell. The fuel elements are packed inside the canister insert. The inside of the canister is filled with an inert gas, argon, in order to slow down and minimise the corrosion inside the canister due to moisture and radiation. The copper canister lid and shell are closed tight. This ensures the long-term isolation of the radionuclides from their surroundings.

Deposition tunnels are excavated into intact bedrock, and then individual copper canisters are installed in vertical holes drilled into the floor of the tunnels at a depth of approximately 430 metres from the ground surface. Bentonite clay compressed into segments is used as the buffer material. The use of bentonite in the disposal

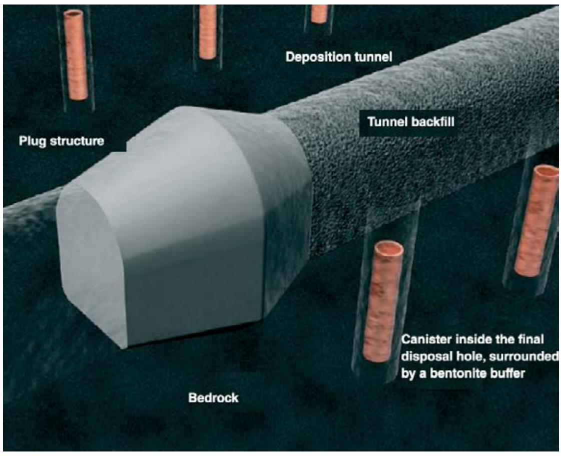


Figure 3-3. The multi-barrier principle for final disposal. The different release barriers supplement each other. The final disposal canister is placed in a vertical hole drilled in the tunnel floor, which has been lined with bentonite buffer segments. Finally, the tunnel is filled with a backfill material, and a reinforced concrete plug structure is cast at the end of the tunnel.

repository is based on its low water conductivity and ability to expand in contact with water. The deposition tunnels are filled with a granular backfill material after the installation of the canisters and buffer material. The central tunnels that connect deposition tunnels will be closed gradually as the final disposal progresses. The technical facilities and connections to the ground surface, such as the driving tunnel and shafts, will be filled at the end of the final disposal operations.

The bedrock isolates the fuel placed in final disposal from the living nature. It protects the canisters from external effects, creates mechanically and chemically stable conditions in the disposal repository and restricts the amount of groundwater that comes into contact with the final disposal canisters. Research results indicate that, in bedrock at a depth of hundreds of meters, groundwater is practically free of oxygen and has a low flow. Therefore, it has a very low corrosive effect on the canisters as well as the spent nuclear fuel. If spent nuclear fuel comes in contact with groundwater, the substances that dissolve from it will mostly remain in the bentonite buffer and bedrock that surround the canisters. In addition, the bedrock effectively stops the direct radiation from the canisters, as two metres of rock is enough to attenuate the radiation to the level of natural background radiation.

3.3 RESEARCH ACTIVITY AND THE REPORTS PREPARED

Posiva has accumulated a great deal of research data on Olkiluoto from several decades. This includes data on the bedrock, water, flora, fauna and weather conditions in the area. Information on the prepared reports is available on Posiva's website *(https://www.posiva.fi/en/index/media/reports.html).*

The technical design of the final disposal solution is essentially based on the information on the conditions deep inside the bedrock and their changes. The properties of Finnish bedrock in terms of final disposal have been studied since the beginning of the 1980s, initially at a general level and for developing the research methods. Later, since 1986, research has been focused directly on determining the properties of bedrock suitable for the final disposal of spent nuclear fuel first in five research sites and later in four sites, of which Olkiluoto, Eurajoki was selected as the final disposal site in 1999. The selection of the site was confirmed by the Finnish Parliament ratifying a decision-in-principle by the Government in 2001.

Research has been carried out primarily on the ground surface, but with the construction of the ONKALO research facility, research at Olkiluoto has also taken place underground. The overground site research includes research hole drilling, research excavations as well as groundwater and environmental research. ONKALO has allowed for studying the bedrock at the final disposal depth. A comprehensive summary of the data collected on the final disposal site over the course of some 20 years is presented in the report Olkiluoto Site Description 2018.

The characteristics of the final disposal site will be disturbed as a result of the construction and operation of ONKALO and the disposal repository. Understanding these disturbances is of utmost importance in order to understand the future development and environmental impacts of the final disposal site and final disposal system. The most recent documentation relating to the final disposal site and impacts from construction and the latest models have been utilised in several analyses and forecast–result assessments that are an essential part of the description of the site.

The technical properties of the final disposal solution and the effects of the rock environment on the substances and structures used have been studied alongside the bedrock research. In addition to Posiva's research, there is plenty of research data produced by SKB, the company responsible for Swedish nuclear waste management, on the properties and behaviour of the final disposal canister and the bentonite that surrounds it.

The properties of bentonite have been studied since the 1970s, and there is plenty of experimental and modelled data on its behaviour in the anticipated bedrock conditions. However, in Posiva's safety concept, the canister is the primary means of isolating the radionuclides from the environment. Both in vertical and horizontal deposition, the bentonite buffer surrounding the canister has essential safety significance in terms of the canister durability and possible leaks.

The feasibility of the final disposal solution has been tested in small-scale and component-specific tests on the ground surface and in ONKALO as well as in a full-scale final disposal system test in the FISST project. The ONKALO demonstration tunnel 2 was equipped with hundreds of measurement sensors and canisters were installed in two test deposition holes of the tunnel surrounded by bentonite buffers. The tunnel was filled with bentonite blocks and pellets and closed with a reinforced concrete plug. The thermal elements inside the canisters generate thermal energy equivalent to the residual heat from fuel. The test is in a follow-up stage and, among other things, it provides information on the development of temperature, pressure and bentonite water absorption and oxygen consumption.

The mutual objective of the research, development and technical design relating to final disposal is finding a solution for isolating nuclear waste such that no health or environmental harm is expected in the future. However, a considerable part of the research has focused on determining the causes and consequences of situations in which the isolation does not function as expected. These studies have focused particularly on the solubility and travel characteristics of radioactive substances in the bentonite and rock environment and the resulting radiation exposure. The significance of possible releases has been assessed with safety analyses, several of which have been made since 1982. The safety case enclosed with the final safety assessment (SC-OLA) is presented in connection with the operating licence application for the encapsulation plant and disposal facility.

The social and economic impacts have also been studied. Several follow-up studies and reports have been made based on the follow-up programmes presented in the EIA reports completed in 1999 and 2008. The reports include a study tracking Finnish people's attitudes to energy *(Finnish Energy Attitudes 2011 & 2020),* the opinion polls carried out in Eurajoki and the neighbouring municipalities as part of the KYT2010 programme (*Kari et al. 2010 & Litmanen et al. 2010),* an image survey (Corporate Image Oy 2007) and a report on financial impacts (Laakso et al. 2007).

3.4 MAXIMUM QUANTITIES OF SPENT NUCLEAR FUEL

The maximum amount of spent nuclear fuel accumulated from the current Olkiluoto and Loviisa power plant units (Olkiluoto 1, 2 and 3 and Loviisa 1 and 2) is 6,500 tonnes of uranium (tU). If the service life of the existing plant units is extended at Olkiluoto, more spent nuclear fuel may accumulate, but separate permits will be applied for in that case. The extension of the service life of the Loviisa plant units has been taken into account in the current maximum amount.

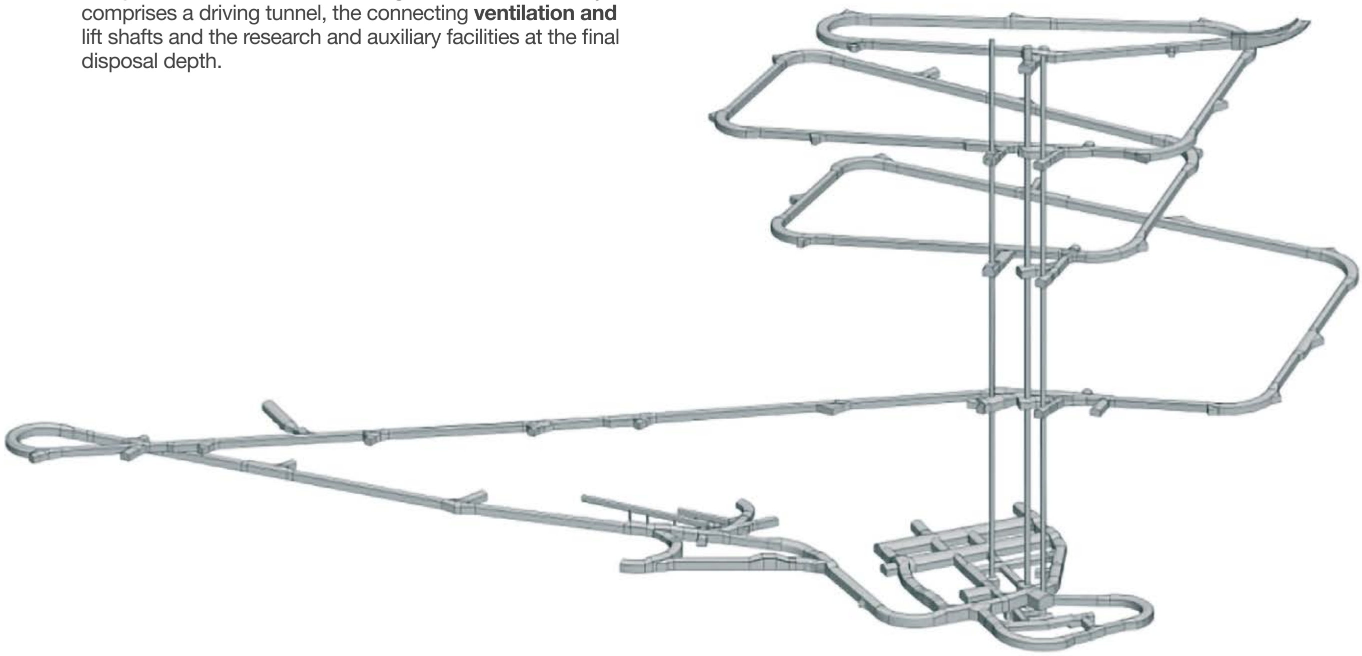
The accumulated amount of spent nuclear fuel is generally dependent on the energy generated by the nuclear power plants and on the fuel discharge burn-up, i.e.

- plant unit power levels,
- duration of operating life,
- capacity factor,
- fuel properties.

3.5 DESCRIPTION OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY AND THE RELATED TECHNOLOGY

The principles behind the encapsulation plant

■ **Figure** 3-4. The ONKALO underground research facility comprises a driving tunnel, the connecting **ventilation and** lift shafts and the research and auxiliary facilities at the final disposal depth.



and disposal facility and the description of their operation are presented in Appendix 5 to the operating licence application.

3.5.1 CONFIRMING RESEARCH STAGE – ONKALO RESEARCH FACILITY

The research stage preceding the construction licence application has been called the confirming research stage. The primary objective of this stage was to study the bedrock and obtain information on confirming the final disposal site's properties and information for the detailed planning of the disposal facility. For this purpose, the ONKALO research facility (Figure 3-4) that extends to the final disposal depth was built at Olkiluoto. Later, "ONKALO" started to refer to the entire disposal repository.

The ONKALO undergound research facility comprised a spiral driving tunnel, personnel and ventilation shafts, research, testing and demonstration facilities as well as technical facilities. ONKALO was designed and implemented such that it could later be used as part of the disposal facility. In connection with starting construction subject to a construction licence, the underground research facility was included as part of the disposal facility.

After the construction licence was granted in 2015 and construction subject to the construction licence started in 2016, development and research efforts have been continued in ONKALO. It can be considered that the most significant one is the FISST (Full scale In-Situ System Test) project, in which full-scale engineered release barriers were installed in deposition holes in a test deposition tunnel excavated for the test along with follow-up systems that still continue their monitoring. The test provides information on how the installed final disposal concept behaves at a stage following closure.

Currently, a joint functional test is being prepared in ONKALO for further testing of the implementation of the entire final disposal system without the fuel to be placed in final disposal. The joint functional test will use the practices, equipment and concepts which are intended for starting the final disposal and demonstrate the functionality of the practices and equipment.

3.5.2 CONSTRUCTION STAGE

The planning of the encapsulation plant and disposal facility has progressed according to plans also during the construction stage. A ventilation building that serves the operation of ONKALO and, later, the encapsulation plant

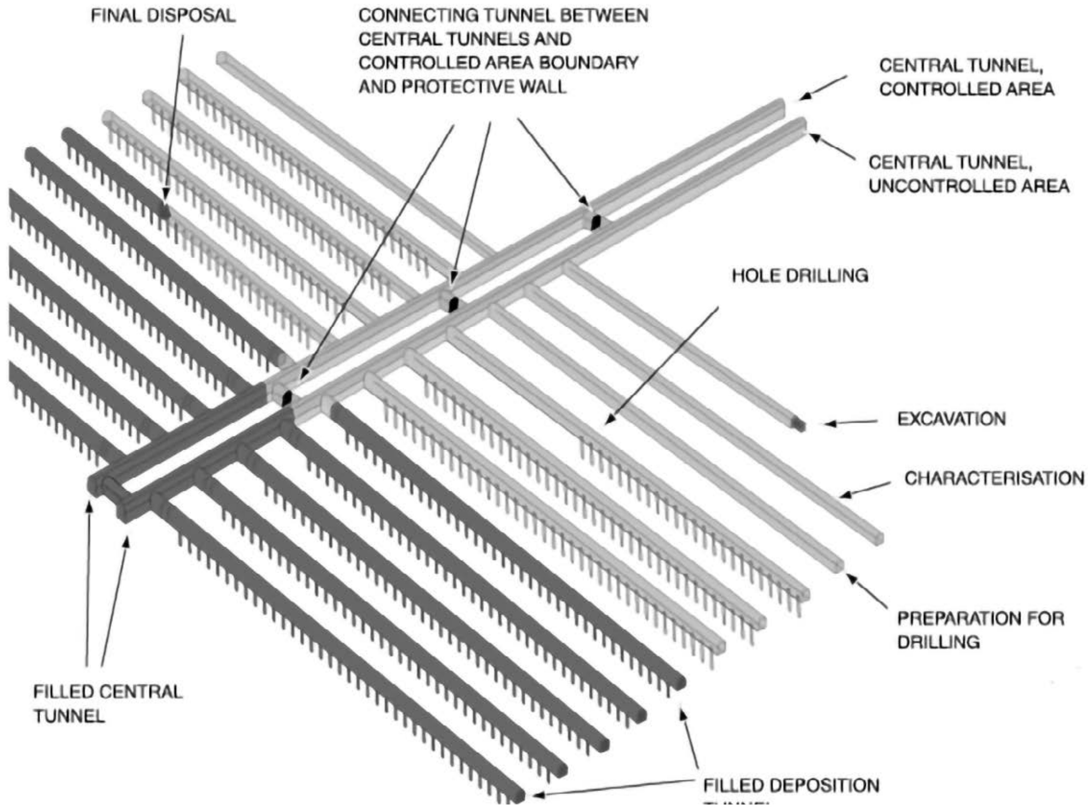


Figure 3-5. The gradual construction of the deposition tunnels

and disposal facility, was completed in 2011. Its systems will also be used for the ventilation of the disposal facility.

The prototypes of equipment required in final disposal operations were manufactured first before the design and manufacture of final production equipment. The prototype equipment was used e.g. in the installations for the FISST test in the ONKALO demonstration tunnel.

Some of the overground buildings have been constructed already during the ONKALO stage. They include the research building, storage building, project office, tunnel engineering building, service and storage building, washing building and engineering building. The rest of the overground structures have been implemented during the implementation of the disposal facility section.

The underground facility section comprises access routes that extend deep into the bedrock, the tunnels and deposition holes for the placement of the final disposal canisters, and the necessary underground auxiliary facilities and access connections. From the ground surface to the disposal repository, there is a driving tunnel and four vertical shafts for ventilation, personnel traffic and canister transfers. Some of the construction work for the disposal repository was completed already during the ONKALO construction stage. ONKALO was designed such that it can act as an access route to the disposal repository. In the final disposal stage, ONKALO's inlet air and exhaust air shafts will act as the inlet air shaft for the entire disposal facility and the exhaust air shaft for the radiation controlled area, respectively, and the technical facilities will act as the technical facilities for the radiation controlled and non-controlled area. The work methods and materials used in ONKALO's construction were selected such that they are acceptable also in terms of the disposal repository and final disposal operations.

The positioning of the disposal repository in the underground disposal facility is based on a rock classification through research. Chapter 8 describes how the site's suitability for the construction of the encapsulation plant and disposal facility is assessed. The deposition tunnels and technical facilities are connected via a central tunnel network. According to plans, the excavation of only a small part of the

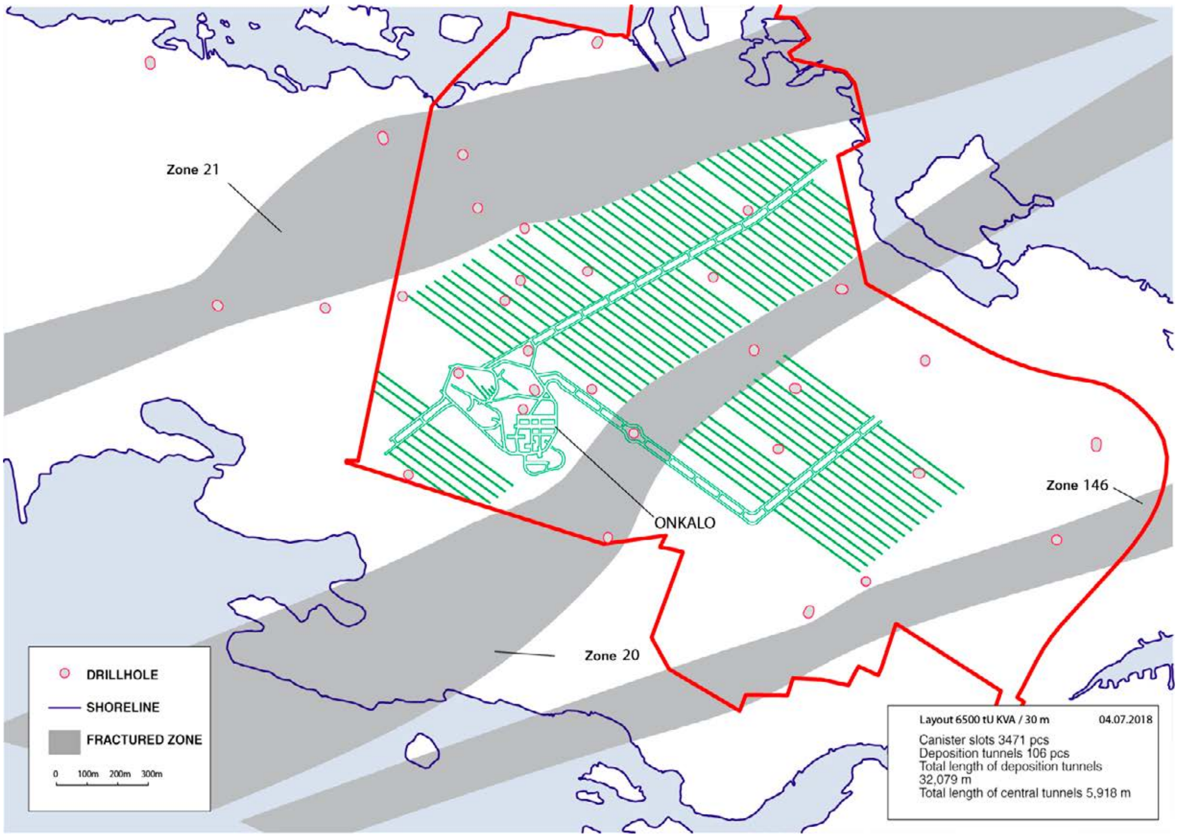


Figure 3-6. The disposal repository intended for 6,500 tU of spent fuel positioned in the local detailed plan area with the border of the local detailed plan area in red. The figure also shows in grey the most significant rock structures that limit the positioning based on current knowledge.

deposition tunnels will be finished before final disposal is started. After this, the tunnel system will be gradually expanded along with the final disposal operations. The underground facilities will be divided into separate compartments such that the excavation of the disposal repository and other construction work and the actual final disposal will occur separately and at a sufficient distance apart. When excavating the central tunnels and deposition tunnels, a sufficient safety distance must be maintained between the excavation machine and the deposition tunnels in use. Moreover, some of the central tunnels will be backfilled and closed already during the operating phase of the disposal repository. The figure (Figure 3-5) shows an example of the gradual construction of the deposition tunnels.

The excavation of the deposition tunnels has used a precisely defined drilling and blasting technique that aims at minimising any damage to the rock caused by the excavation. Alternatively, as technology advances in the future, tunnel construction can use so-called mechanical excavation that does not require blasting. The rock material brought up from the underground disposal repository is stored in a quarry material dumping area at Olkiluoto.

The figure (Figure 3-6) presents a principle drawing of the disposal repository based on the current understanding for the final disposal of 6,500 tU at Olkiluoto. The surface area required for the underground facility section is approximately 150 hectares for the final disposal of 6,500 tU of fuel.

3.5.3 TRANSFERS AND TRANSPORTS OF SPENT NUCLEAR FUEL

Spent nuclear fuel is stored at the interim storages of Fortum's Loviisa nuclear power plant and TVO's Olkiluoto nuclear power plant for approximately 40 years but at least 20 years before its final disposal. By this time, the spent nuclear fuel has cooled enough for placement in final disposal. From the interim storages, the spent nuclear fuel is transported to the encapsulation plant and disposal facility at Olkiluoto in special transport packaging.

The transportation of spent nuclear fuel (KPA) is subject to strict national and international regulations and agreements. In Finland, spent nuclear fuel transports require a licence, which must be applied for from the Radiation and Nuclear Safety Authority (STUK). STUK inspects the transport plan, structure of the transport container, qualifications of the transport personnel, safety arrangements and preparedness for accidents.

Transport containers and transfer casks

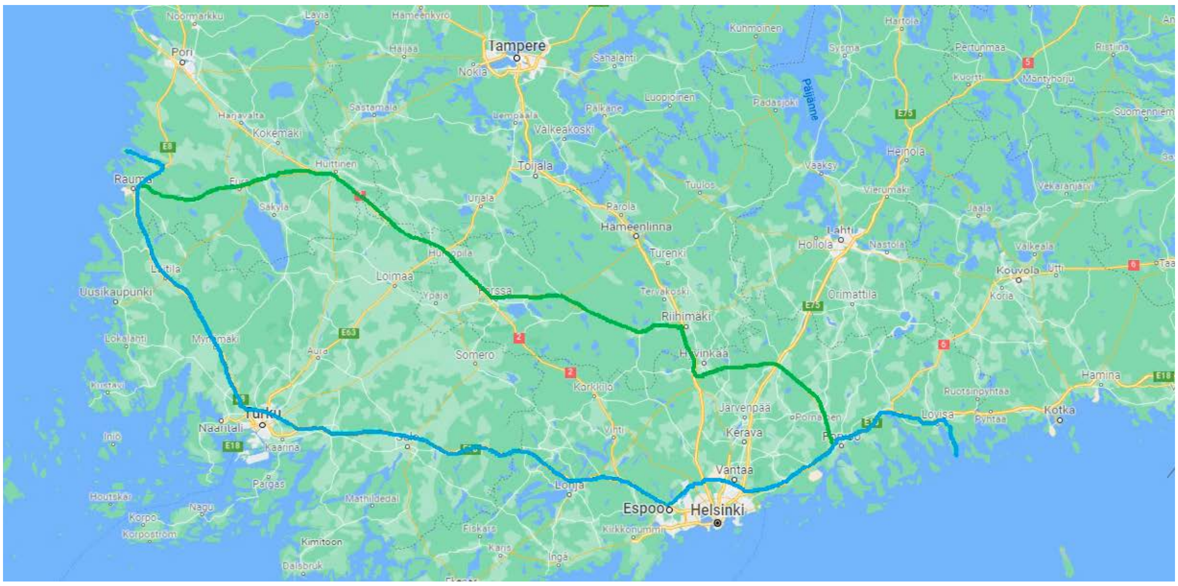
Fuel may be transported inside a dry container or one filled with water. Around the world, most long-distance spent nuclear fuel transports nowadays use a dry container, so Posiva has also decided to use a dry container for fuel transports from Loviisa. However, it is simpler to use a container filled with water for internal transfers within the plant area, so TVO's fuel will be transferred to the encapsulation plant in a wet container.

High requirements have been set for transport containers, their handling, preparedness for accidents, and documentation. The guiding principle is that the transport container must not lose its radiation protection properties even in the worst conceivable accident. During transportation, the spent nuclear fuel inside the transport container must remain subcritical under all conditions. Transport containers are subject to stricter requirements than conventional transport equipment, and they must meet strict requirements in case of exceptional circumstances. Among other things, the transport container must withstand the following:

- a drop from a height of 9 m onto an immovable surface at the most unfavourable angle of impact
- a drop onto a steel bar 0.15 m in diameter from a height of 1.0 m
- a minimum of 30 min in a thermal environment caused by a fire with a flame temperature of 800°C
- immersion at a depth of 200 m for at least one hour. (IAEA 2018)

Transfers of spent nuclear fuel from the Olkiluoto plant

Transfers of spent nuclear fuel from the Olkiluoto KPA storage to the encapsulation plant will be carried out using purpose-built transfer casks filled with water, which are owned by TVO. TVO is already using a transfer cask for the OL1–2 fuel and is procuring a cask for the OL3 fuel. Furthermore, Posiva can use the existing transfer equipment for its transfers.



■ **Figure** 3-7. Route alternatives for road transports from Loviisa to Olkiluoto

The transfers of spent nuclear fuel from the Olkiluoto plant to the encapsulation plant are simpler than transports from Loviisa, as the distance is short and there are no public roads on the route. Fuel transfers from the interim storage to the encapsulation plant will use the current road connections and, in part, new roads in the Olkiluoto power plant area. The heavy transport route required for the transports of spent nuclear fuel will be taken into account when designing the road system. Transfers and the related licencing will be carried out according to the requirements of Guide YVL D.3.

Transports from Loviisa to Olkiluoto

According to Posiva's current production plan, the final disposal of fuel from Loviisa will begin in the 2040s. Therefore, no specific plans have been made regarding the Loviisa transports. Rather, the possibilities for implementing different alternatives have been examined.

The examined alternative modes of transport for spent nuclear fuel from Loviisa to Olkiluoto are transports by road, sea and a combination of the two. Ship transports may include vehicle transports by land or short transfers that take place in Loviisa and Olkiluoto.

The number of fuel transports depends on the amount of nuclear fuel, size of the transport packaging and mode of transport. Each transport requires preparing a transport plan (Guide YVL D.2), which specifies how the transport arrangements are implemented in accordance with the requirements included in codes applicable to the transports. The transport plan must be submitted to STUK for approval no later than three months before the transport(s). Preparedness and security plans will also be prepared for the transports.

For road transports, the spent nuclear fuel transport packaging is loaded by crane onto a special combination of vehicles at the spent nuclear fuel store of the nuclear power plant. A dedicated bracket is obtained for each transport packaging that enables lowering the packaging onto the vehicle, turning the packaging horizontally and securing it in place. The bracket can also be used for the storage of the transport packaging. A full trailer can fit under the bracket, and after securing is complete, the legs of the bracket are lifted up for transport. The container and transport platform are protected with a weather cover during the transport. Transports can be completed with heavy transport equipment that is suitable for 150–200 tonne transports and that has been inspected for this purpose. Transports will take place as supervised transports; the transport will be escorted by appropriate personnel, such as the police or a supervisor from STUK.

The aim is to primarily carry out the transports by main roads, as they have a good load-bearing

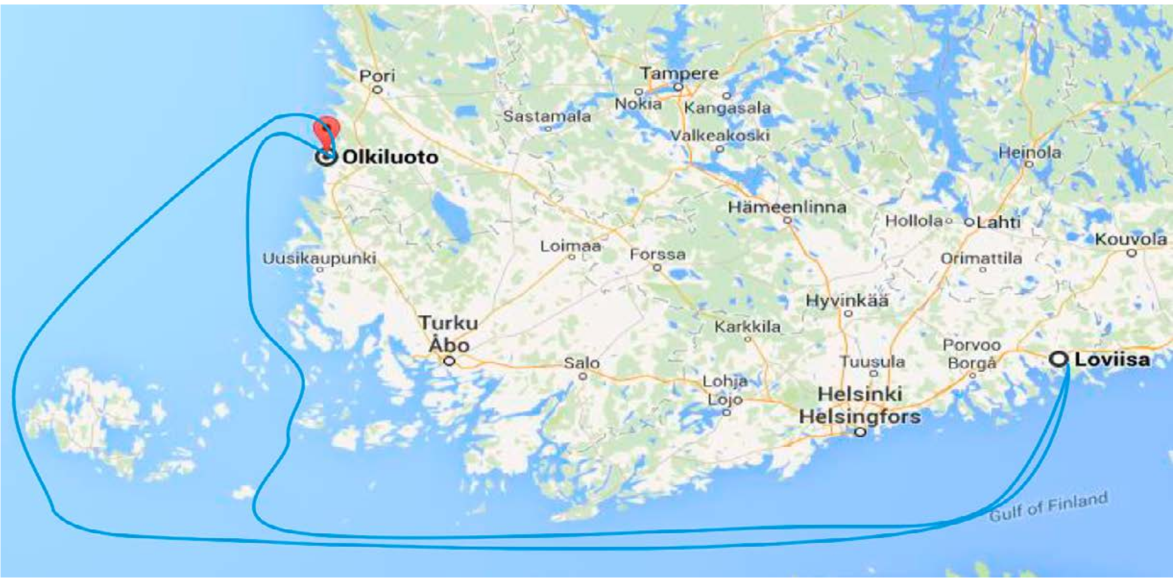


Figure 3-8. Sea route alternatives via the Archipelago Sea or Sea of Åland.

capacity and there are no weak bridges or low underpasses on the route. Technically, the best option for transport is a motorway because it has a good load-bearing capacity, there is no oncoming traffic and there are few junctions. For road transports, the two most significant different types of route options would be a coastal route and an inland route (Figure 3-7).

In sea transports, the aim is to plan the transport routes to be as short as possible. It is possible to build a suitable port at the Loviisa plant site. Furthermore, the port of Valko in Loviisa is located at a reasonable distance from the plant area. Similarly, at Olkiluoto, the aim is to use a port within or near the plant area. There are several alternatives for the sea transport route (Figure 3-8). The final choice of route will follow the transport plan.

Sea transports can be completed with a vessel similar to the M/S Sigrid, which is designed for nuclear fuel transports and owned by SKB, the company responsible for Swedish nuclear fuel and nuclear waste management.

Loading requires a suitable port and a transport vehicle that can transfer each transport packaging along with the transport bracket from the power plant to the ship and from the ship to the encapsulation plant and disposal facility at Olkiluoto. In principle, the transfer vehicle is similar to the road transport equipment. Once the transport packaging and its bracket have been loaded onto the ship, the bracket is removed from the transfer vehicle and secured onto the ship's deck. The transfer vehicle is supposed to travel onboard the ship.

The transfers of spent nuclear fuel from the Olkiluoto KPA storage to the encapsulation plant are described in more detail in Posiva's operating licence documentation submitted to STUK. Spent fuel transports from the Loviisa KPA storage to the encapsulation plant at Olkiluoto are described in more detail in the appendices "Analysis of the risks related to transport" and "Report on nuclear waste management" to this operating licence application.

3.5.4 OPERATING PHASE

Processing of spent nuclear fuel at the encapsulation plant

The most important overground building in Posiva's plant complex is the encapsulation plant. The most important parts of the encapsulation plant are the nuclear fuel reception room, the handling cell for encapsulating the nuclear fuel, the welding station for closing the canister lid, the weld seam machining and inspection station, the fuel transport container and canister transfer corridors, the control room, the canister lift and the systems relating

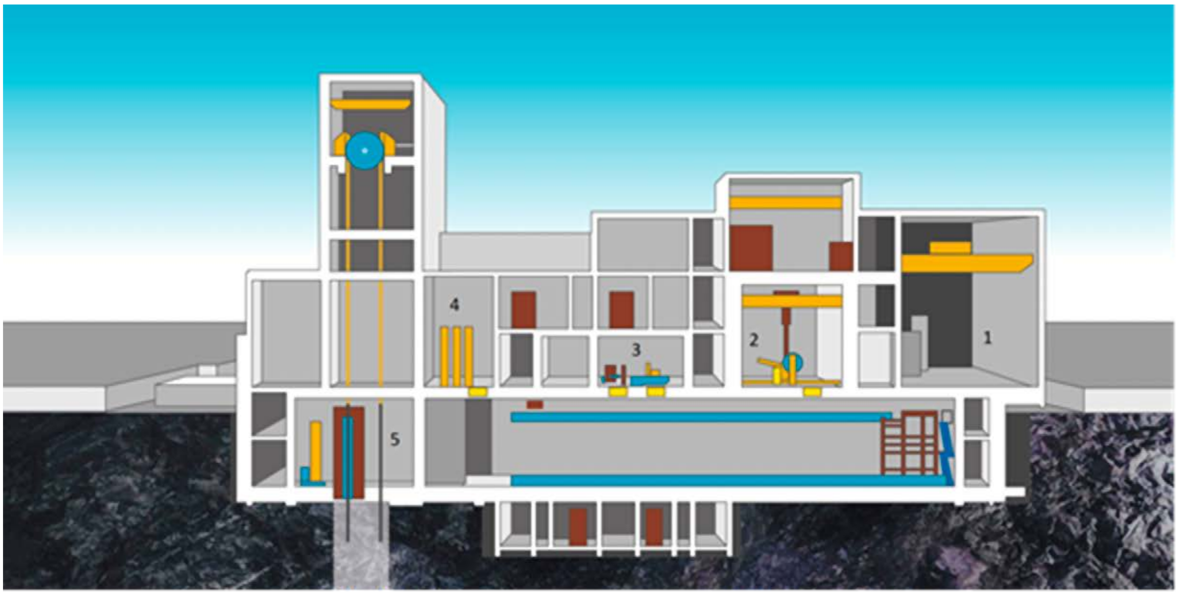


Figure 3-9. Longitudinal cross-section of the encapsulation plant. The fuel reception room (1) is on the right. To the left, there are the fuel handling cell (2), copper lid welding station and weld seam machining and inspection station (3). On the left side, there is the new canister reception and storage room (4) and canister lift (5).

to the operation of the encapsulation plant. The functions of the encapsulation plant include the transport packaging reception, encapsulation of nuclear fuel, fixing the canister lid by welding and inspection of the weld seam. There is a direct connection from the encapsulation plant to the below disposal facility via the canister lift. The cross-section of the encapsulation plant is shown in the figure (Figure 3-9).

The encapsulation plant is designed such that it can process the spent fuel from the current nuclear power plant units of Posiva's owners. The transport vehicle is driven into the reception room, the shock absorbers are removed from the transport packaging, the transport packaging is raised to a vertical position and transferred either to the storage section for the reception room or the transport packaging transfer corridor. The outer protective cover of the transport packaging is removed, the overpressure is allowed to discharge and a sample is taken from the gas space of the transport packaging. The transport packaging is docked into the handling cell and the protective cover of the handling cell is opened. Then, the radiation protection lid of the transport packaging is lifted into the handling cell. The fuel elements are transferred from the transport packaging to the fuel drying station. The fuel drying system allows for removing any moisture accumulated in the fuel elements during interim storage and transportation before the fuel elements are placed inside the final disposal canister, if the fuel is brought into the plant in a transfer cask filled with water.

After drying, the fuel elements are transferred individually into the final disposal canister. The air inside the canister insert is replaced with a shielding gas by using a gas exchange dome, the insert lid is screwed in place and its tightness is checked. After the inner lid is secured, the handling cell isolation lid is installed in place and the final disposal canister is detached from the handling cell docking. The copper lid is raised into the welding cell and the final disposal canister is aligned with the welding cell. The canister is docked into the welding station where the copper lid is installed in place and welded by using friction stir welding equipment. The canister weld seam is machined and its quality is inspected visually as well as with ultrasonic and eddy current inspection equipment. After the inspection, the canister can be transferred to the canister storage to wait for transportation into the disposal facility with the canister lift.

Deposition of canisters in the bedrock

The disposal repository is located on one level at a depth of approximately 400–450 metres. At least in the beginning of operations, the final disposal is based on the vertical canister deposition solution (KBS-3V). In addition to this,

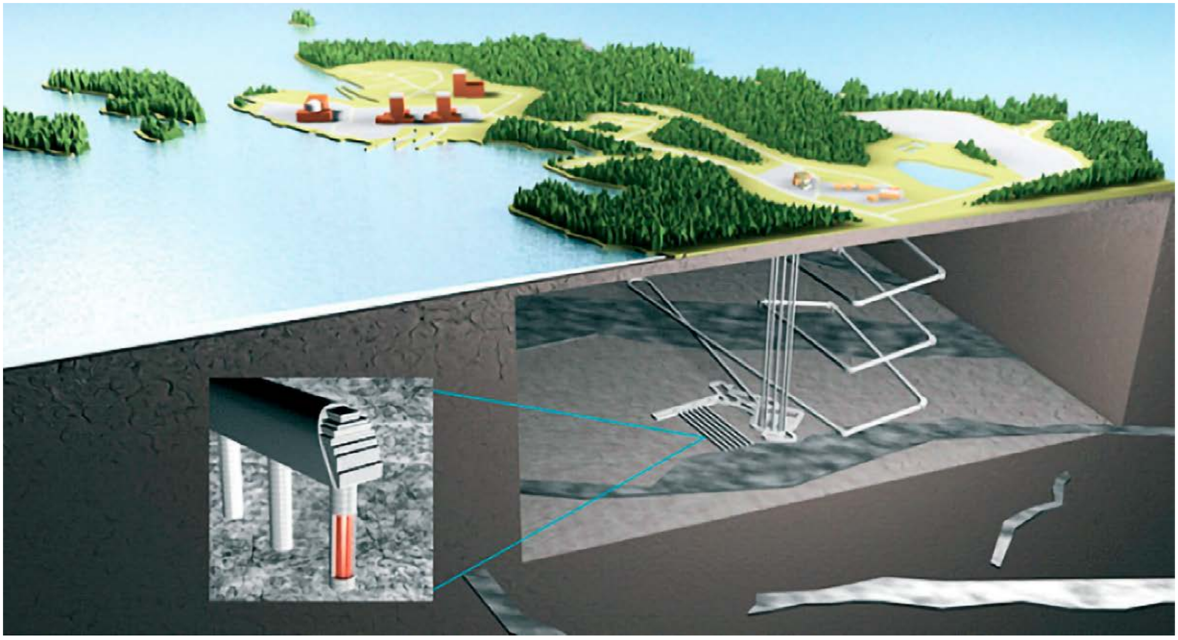


Figure 3-10. A conceptual image of the KBS-3V final disposal solution a horizontal deposition solution (KBS-3H) may be applied, in which the canisters are installed in horizontally drilled tunnels. The KBS-3V solution is shown in the figure (Figure 3-10).

In the vertical deposition solution, vertical deposition holes are drilled into the floors of deposition tunnels for placement of sealed canisters that withstand corrosion. The space between the canister and bedrock is filled with bentonite blocks. Therefore, the canisters will be entirely surrounded by bentonite blocks, which will expand strongly as a result of absorbing water. The deposition tunnels are backfilled after final disposal (installation of canisters and buffer material). Similarly, central tunnels are backfilled as the connection to deposition tunnels is no longer needed.

The primary purpose of backfilling the facilities is to return the final disposal conditions as close to the natural state as possible, for example by preventing tunnels and shafts from becoming primary groundwater flow routes. Furthermore, the purpose of deposition tunnel backfilling is to keep the buffer material in place around the canister and maintain the mechanical stability of the tunnels.

3.5.5 CLOSURE PHASE AND RETRIEVABILITY OF THE NUCLEAR FUEL PLACED IN FINAL DISPOSAL

Final disposal operations generate nuclear waste, i.e. radioactive waste of a nuclear facility, only at the spent nuclear fuel encapsulation plant. Posiva transfers its waste management obligation concerning this low and intermediate level operating waste to TVO, which means that TVO processes, stores and places in final disposal this operating waste according to its established practices as if it was TVO's own operating waste. Radioactive waste is generated when radioactive substances that are released from nuclear fuel contaminate the structures and equipment at the plant. In normal operation, radioactive waste is only generated at the handling cell, decontamination centre of the handling cell workshop, cell ventilation filters and the transport packaging transfer corridor, if the surface of the transport packaging is contaminated.

The principle is that radioactive waste is placed in final disposal as it is generated. All intermediate level waste is solidified before placement in final disposal. Liquid radioactive waste is solidified before placement in final disposal. The low and intermediate level waste is transferred to TVO's plant units for processing and for placement in final disposal at TVO's VLJ cave. The aim is that any high-level waste that is possibly released from the fuel elements is placed inside final disposal canisters and placed in final disposal inside the canisters together with the spent nuclear fuel.

Over the course of the final disposal operations, deposition tunnels are closed as canisters are placed in final disposal. When all of the spent nuclear fuel has been placed in final disposal and the encapsulation plant has been dismantled, the other tunnels and underground facilities will be backfilled using backfill material, and connections to the ground surface will be closed. Once the licensee with a waste management obligation has acceptably closed the disposal repository and issued a payment to the Government for the future monitoring and supervision of the nuclear waste, ownership of and responsibility for the waste is transferred to the Government. According to the Nuclear Energy Act, final disposal shall overall be implemented such that post-disposal monitoring is not required in order to ensure safety.

However, it is possible to retrieve to the ground surface the spent nuclear fuel that has been placed in final disposal in bedrock, provided that sufficient technological and financial resources are available. Retrievability provides future generations with an opportunity to assess the solution in light of their state of knowledge. Retrieval uses the same conventional work technologies and methods as the excavation and construction of the disposal repository. It is possible to retrieve canisters from the disposal repository to the ground surface at all the stages of the project: before the backfilling of the deposition hole, after the deposition hole backfill and before the closure of the deposition tunnel, after the closure of the deposition tunnel and before the closure of all facilities, and after the closure of all facilities. There is a separate report on retrievability in Posiva's operating licence application, as Appendix 11.

4 LEGISLATION AND GUIDELINES APPLICABLE TO THE FINAL DISPOSAL OF NUCLEAR FUEL

Nuclear waste management in Finland is guided by the Nuclear Energy Act (*YEL 990/1987)* and Nuclear Energy Decree (*YEA 161/1988)*, which became effective in 1988 and which define, among other things, the ob-ligations of a nuclear energy producer, implementation of nuclear waste management, licence procedures and supervision rights.

In 1994, the Nuclear Energy Act was amended such that all the nuclear waste generated in Finland must be placed in final disposal in Finland. Furthermore, the Nuclear Energy Act prohibits importing nuclear waste to Finland.

The Radiation and Nuclear Safety Authority Regulation on the Safety of Disposal of Nuclear Waste (STUK Y/4/2018) applies particularly to the encapsulation plant and disposal facility. The regulation applies to the final disposal of spent nuclear fuel and other nuclear waste that originate from a nuclear facility as well as to other radioactive waste deposited in the disposal repository. The Nuclear Energy Decree con-tains provisions concerning the operation of a nuclear waste facility and specifies, among other things, radiation dose limits for the normal op-eration of the facility as well as for operational occurrences and acci-dents.

The nuclear power plant guides (YVL Guides) issued by STUK specify detailed regulations concerning the safety of nuclear facilities. Licen-sees must comply with the YVL Guides, unless they present to STUK another acceptable practice or solution. Guide YVL D.5 concerning the disposal of nuclear waste and Guide YVL D.7 Release barriers of spent nuclear fuel disposal facility apply particularly to the encapsulation plant and disposal facility.

5 THE PERMITS, PLANS, NOTIFICATIONS AND DECISIONS REQUIRED FOR THE PROJECT

5.1 LAND USE PLANNING

The land use planning for final disposal is described in Appendix 3 to the operating licence application, “Description of settlement and other activities on the nuclear facility site and in its vicinity, including land use planning arrangements”.

5.2 ENVIRONMENTAL IMPACT ASSESSMENT AND INTERNATIONAL HEARING

According to the Act and Decree on Environmental Impact Assessment Procedure, facilities designed for the final disposal of radioactive waste are required to organise an environmental impact assessment procedure. According to the Nuclear Energy Act, the environmental impact assessment report must be appended to the decision-in-principle application concerning the construction of a nuclear facility.

Agreements on the assessment of cross-border environmental impacts have been made in the Espoo Convention (Convention on Environmental Impact Assessment in a Transboundary Context). Finland ratified this Convention of the United Nations Economic Commission for Europe in 1995. The Convention entered into force in 1997. A party to the Convention is entitled to participate in an environmental impact assessment carried out in Finland if the harmful environmental impacts of the project being assessed are likely to affect the state in question. Similarly, Finland is entitled to participate in the environmental impact assessment of a project located within another state if the impacts of that project are likely to affect Finland.

The EIA procedure for the final disposal of spent nuclear fuel was carried out in 1998–1999. Posiva updated the information of the EIA report prepared at that time in the first half of 2008. In 2008–2009, Posiva also carried out a completely new EIA procedure. This EIA procedure examined an expansion of the disposal facility for the deposition of a total of 12,000 tU instead of the previously planned 9,000 tU. The EIA procedures also included an international hearing procedure according to the Espoo Convention.

This report is the update to the environmental impact assessment report mentioned in Posiva’s construction licence conditions, which updates the project information. The previous such update was submitted as part of Posiva’s construction licence application.

5.3 DECISIONS AND LICENCES ACCORDING TO THE NUCLEAR ENERGY ACT

5.3.1 DECISION-IN-PRINCIPLE

The spent nuclear fuel encapsulation plant and disposal facility is a nu-clear facility of considerable general significance according to the Nu-clear Energy Act, the construction of which requires a project-specific Government decision-in-principle on the construction project being in the overall interest of society.

A decision-in-principle is sought with an application to the Government. The processing of a decision-in-principle application is not based solely on the documentation submitted by the applicant. Instead, the au-thorities obtain reports specified in the Nuclear Energy Decree as well as other reports they deem necessary that examine the project from more general bases. In order to process a decision-in-principle application, the Ministry of Economic Affairs and Employment (TEM) requests an opinion from the municipal council of the planned facility’s municipality of location and the neighbouring municipalities as well as from the Ministry of the Environment and the other authorities speci-fied in the Nuclear Energy Decree. Furthermore, the Ministry must ob-tain a preliminary safety assessment on the project from STUK.

Before a decision-in-principle is made, the licensee must publish a gen-eral report prepared according to TEM’s instructions and inspected by TEM on the facility project, the assessed environmental impacts of the facility and its safety such that the report is publicly available. The EIA report must be appended to the decision-in-principle application.

TEM must reserve an opportunity for people living close to the nuclear facility, as well as the neighbouring municipalities and local authorities, to present their opinions on the project before the decision-in-principle is made. Furthermore, the ministry must organise a public event at the facility's planned municipality of location during which opinions on the project can be voiced. The opinions must be brought to the attention of the Government.

The Government considers making a decision-in-principle under Section 14 of the Nuclear Energy Act. It is a necessary requirement for a favourable decision-in-principle that the municipality of location sup-ports the planned nuclear facility project. In its consideration, the Government pays particular attention to the following:

- the necessity of the nuclear facility project for the country's supply of energy,
- the suitability of the planned nuclear facility site and the environmental impacts of the nuclear facility,
- organisation of nuclear fuel and nuclear waste management.

The decision-in-principle made by the Government will be subjected to debate in Parliament. The Parliament may either reverse the decision-in-principle or approve it, but it cannot alter its contents. Before a decision-in-principle becomes effective, the licensee must not conclude any financially significant procurement contracts that are related to the construction of the facility. In December 2000, the Government made a decision-in-principle concerning the construction of a disposal facility. This decision-in-principle applies to the spent nuclear fuel generated during the operation of the Loviisa 1 and 2 and Olkiluoto 1 and 2 plant units up to a maximum total quantity of approximately 4,000 tU. In January 2002, the Government made a separate decision-in-principle according to which the disposal facility can be constructed with an extension such that the spent nuclear fuel from the new Olkiluoto 3 unit, amounting to a maximum of 2,500 tU, can also be placed in final disposal there. Finally, in May 2010, the Government made a separate decision-in-principle on the expansion of the disposal facility for the Olkiluoto 4 unit; the decision-in-principle expired in 2015 as the Olkiluoto 4 project was terminated by the decision of its owners.

Therefore, the maximum quantity of spent nuclear fuel to be placed in the disposal facility is 6,500 tU, and Posiva received a construction licence for this quantity in November 2015.

5.3.2 CONSTRUCTION LICENCE

A decision-in-principle by the Government is followed by the actual licence procedure. The licence for constructing and operating a nuclear facility is issued by the Government. A licence can be granted if the construction of the nuclear facility has been considered to be in the overall interest of society in the decision-in-principle approved by the Parliament and if the requirements for granting the construction licence for a nuclear facility set forth in Section 19 of the Nuclear Energy Act are met.

For the construction licence processing concerning the encapsulation plant and disposal facility, the applicant must submit to the authorities several reports that demonstrate the safety of the plant and facility in accordance with the Nuclear Energy Act and Decree. For example, these include a report on the quality and maximum quantity of nuclear waste stored in the nuclear facility, a report on the environmental impacts of the nuclear facility and an account of the design basis which the applicant intends to follow in order to prevent environmental damage and limit the environmental load.

In November 2015, the Government granted Posiva a construction licence for the encapsulation plant and disposal facility.

5.3.3 OPERATING LICENCE

The operation of a nuclear facility requires an operating licence granted by the Government. A licence for operating a nuclear facility can be granted after a licence for its construction has been granted provided that the requirements set forth in Section 20 of the Nuclear Energy Act are met. These requirements include the following:

- the operation of the nuclear facility is arranged such that occupational safety, population safety and environmental protection are considered appropriately,
- the methods available to the applicant for arranging the nuclear waste management are sufficient and appropriate,

- the applicant has sufficient expertise available and, in particular, the competence of the operating staff and the operating organisation of the nuclear facility are appropriate,
- the applicant is considered to have the financial and other prerequisites to engage in operations safely and in accordance with Finland's international contractual obligations.

Operation of the nuclear facility shall not be started on the basis of the licence granted for it until STUK has ascertained that the statutory requirements are met and TEM has ascertained that provision for the cost of nuclear waste management has been arranged in accordance with the law.

In Finland, an operating licence for a nuclear facility is always granted for a fixed period. When considering the length of the licence, particular attention is paid to ensuring safety and the estimated duration of operations. STUK may suspend the operation of a nuclear facility if it is necessary for ensuring safety. According to the Nuclear Energy Act, disposal of nuclear waste is considered implemented when STUK has confirmed the nuclear waste to be permanently disposed of in a manner it has approved.

This report is part of an operating licence application for the spent nuclear fuel encapsulation plant and disposal facility which Posiva submits to the Government. Posiva aims at starting final disposal in approximately 2025.

5.3.4 DECOMMISSIONING LICENCE

After terminating the operation of a nuclear facility, the holder of the operating licence referred to in Section 20 shall be under an obligation to undertake measures to decommission the nuclear facility in accordance with the plan for and the requirements set on decommissioning referred to in Section 7 g as well as apply for a licence for decommissioning of the nuclear facility. The licence shall be applied for well in advance so that the authorities have adequate time to assess the application before the termination of the operating licence of the nuclear facility.

A licence for decommissioning of a nuclear facility may be granted if:

1. the nuclear facility and its decommissioning meet the requirements relating to safety in accordance with this Act and if the safety of the employees and the population as well as environmental protection have been duly taken into account;
2. the methods available to the applicant for the decommissioning of the nuclear facility as well as other nuclear waste management are adequate and appropriate;
3. the applicant has the necessary expertise available, and especially if the competence of the nuclear facility personnel and the organisation of the nuclear facility are appropriate and suitable for decommissioning;
4. the applicant has the financial and other necessary requirements for carrying out the decommissioning safely and in accordance with Finland's international contractual obligations; and
5. the nuclear facility and its decommissioning fulfil the principles provided in Sections 5, 6, 6 a, 6 b and 7.

The decommissioning of a nuclear facility may not be started before the granting of the related licence unless otherwise provided in the other licences of the licence holder. The decommissioning of a nuclear facility may not be started on the basis of the licence granted for it until:

1. the Radiation and Nuclear Safety Authority has ascertained that the nuclear facility meets the safety requirements for decommissioning, that the security and emergency arrangements are sufficient, that the control necessary to prevent the proliferation of nuclear weapons has been arranged appropriately, and that the nuclear facility operator has arranged, in accordance with the related provisions, indemnification regarding liability in the event of nuclear damage; and
2. the Ministry of Economic Affairs and Employment has ascertained that provision for the costs of nuclear waste management has been arranged in accordance with the provisions of Chapter 7.

Posiva's encapsulation plant will be decommissioned in the early decades of the 22nd century, at which time Posiva must apply for a licence for this. The disposal facility will be closed permanently according to dedicated procedures.

5.4 DECLARATIONS ACCORDING TO THE EURATOM TREATY

The European Atomic Energy Community (Euratom) Treaty requires a member state to submit to the Commission the plans concerning the disposal of nuclear waste (Article 37) for assessing whether the implementation of the plan will result in the radioactive contamination of water, soil or air in the area of another member state. Furthermore, according to Article 77, the Commission's duties include maintaining safety control with the aim of ensuring that spent nuclear fuel, for instance, is not transferred to a location other than declared and that the operator submits to the Commission a declaration of the facility's technical details (Article 78) and a declaration of investments (Article 41) for the purpose of safety control. Posiva has taken care of and will take care of submitting all the required declarations to the Commission.

5.5 OTHER PERMITS

During its construction and operations, the spent nuclear fuel encapsulation plant and disposal facility requires other permits, including a building permit and a permit for temporary storage of explosives. These permits will be applied for before the start of the related activity in accordance with the valid national and municipal regulations.

A building-specific building permit is sought for each building from the municipal building committee. Among others, building permits have been applied for the ventilation building, research building and the storage and service buildings.

According to the decision by the Regional State Administrative Agency for Southern Finland (ESAVI-0000426-05.14.00-2011, 19 Jan 2011) and the statement by the ELY Centre on 28 June 2016, the encapsulation plant and disposal facility do not require an environmental permit.

There is an environmental permit valid until further notice for storing and crushing quarry material. The permits for the underground research facility ONKALO® have been applied for as a dedicated unit. A building permit was sought for ONKALO® and the supporting overground construction in the area from the municipality of Eurajoki, and the municipal building committee issued the permit on 12 August 2003. The building permit is valid for five years. Posiva applied for an extension permit in May 2008 and again in December 2011. The latest extension permit was issued on 18 September 2020 and it remains valid until 18 September 2023. The construction licences for the encapsulation plant and disposal facility are valid until 12 June 2024.

According to Section 8 of the Nuclear Energy Act, transportation of spent nuclear fuel requires a licence, and a transport licence must be applied for according to Sections 56–60 of the Nuclear Energy Decree. The necessary licences for the transportation of nuclear materials and nuclear waste in Finland are issued by STUK.

Furthermore, transports of spent nuclear fuel and the involved technology are regulated, among others, by:

- Act on the Transport of Dangerous Goods *(719/1994*),
- Government Decree on the Transport of Dangerous Goods by Road (194/2002) and Decree of the Ministry of Transport and Communications on the Transport of Dangerous Goods by Road *(369/2011),*
- Government Decree on the Transport of Dangerous Goods by Rail *(195/2002)* and Decree of the Ministry of Transport and Communications on the Transport of Dangerous Goods by Rail *(370/2011),*
- Decree on the Transport of Dangerous Goods in Packaged Form by Sea *(666/1998),*
- STUK Guide YVL D.2, "Transport of nuclear materials and nu-clear waste".

The transport cannot be commenced until STUK has ascertained that the transport equipment and transport arrangements and the arrangements for physical protection and emergency planning meet the requirements set for them and provision has been made for indemnification regarding liability in case of nuclear damage. Applying for the first transport licence will be relevant in approximately the 2040s as transports from the spent nuclear fuel interim storage of the Loviisa power plant begin. Transfers of Olkiluoto spent nuclear fuel from the interim storage to the encapsulation plant will take place as internal transfers within the power plant area.

The operating licences for the Olkiluoto nuclear power plant units authorise the handling and storage of waste generated from Posiva's operations. The permits for the Olkiluoto VLJ cave and underground disposal facility will take into account the final disposal of Posiva's operational waste.

6 TRANSPORTS OF SPENT NUCLEAR FUEL AND OTHER TRAFFIC

6.1 TRANSPORTS OF SPENT NUCLEAR FUEL AND OTHER TRAFFIC

6.1.1 ASSESSMENT METHODS

The most significant traffic impacts from the project are the result of the construction and operation of the encapsulation plant and disposal facility as well as the transports of spent nuclear fuel. The changes due to the transports on the current traffic volumes as well as the equipment and routes used are presented. The noise impacts and effects on comfort from traffic have been assessed based on the traffic changes affecting residential areas. The necessary changes to the regions' traffic arrangements and their effects have been assessed.

Spent nuclear fuel is brought to the encapsulation plant and disposal facility from TVO's and Fortum's nuclear power plants. According to plans, nuclear fuel transports from Loviisa to Olkiluoto will take place as road or sea transports or their combination. This report presents an assessment based on the prepared accounts on the safety and environmental impacts of the spent nuclear fuel transport alternatives.

The radiation doses resulting from the transports have been assessed by utilising the report "Käytetyn ydinpolttoaineen kuljetusten riskiselvityksen päivitys Posivan käyttölupahakemusta varten" (Update to the risk assessment of spent nuclear fuel transports for Posiva's operating licence application) *(Suolanen et al. 2021).* The report examines the risks relating to transports of spent nuclear fuel from the Loviisa nuclear power plant to the Olkiluoto disposal facility in terms of radiation safety. The examination has involved the comparison of radiation impacts and risks relating to the different route alternatives and modes of transport.

The work involved modelling in detail the gas-cooled CASTOR-440/84M transport container and conducting radiation protection calculations with the Serpent model for determining the dose rate outside the container. According to the calculations, the total dose rate at a 2-m distance from the container shell is 0.03 mSv/h, which is clearly below the dose limit of 0.1 mSv/h presented by the IAEA.

In normal transports, the highest radiation doses are incurred by personnel during the handling of the transport container. The radiation doses incurred by the population during the transport are lower than the doses incurred by the personnel. In road transports, the annual total radiation dose is 0.01 manSv for the coastal route and 0.013 manSv for the inland route. In sea transports, the total annual radiation dose is 0.01 manSv for transports via the port of Valko and 0.007 manSv for transports that depart directly from Hästholmen.

Risks relating to transports have been previously reviewed in 2004 in the report "Käytetyn ydinpolttoaineen kuljetusriskitarkastelun päivitys" (Update to the spent nuclear fuel transport risk review) *(Suolanen et al. 2004)* and in 2012 in Posiva's construction licence application in the report "Käytetyn ydinpolttoaineen kuljetusten riskienhallinta" (Risk management in spent nuclear fuel transports) *(Suolanen 2012).*

Transport and road traffic impacts have been reviewed on the roads whose traffic is affected by the project.

6.1.2 IMPACTS FROM TRANSPORTS AND TRAFFIC

The main settlement in Eurajoki is located along national road 8 between Rauma and Pori. Olkiluodontie, the road leading to Olkiluoto (road 2176 Lapijoki – Olkiluoto) diverges from national road 8 at Lapijoki. The distance from the intersection to Rauma is approximately seven kilometres and to Pori approximately 40 kilometres. In addition, Olkiluoto can be accessed from Rauma through Sorkka. From the centre of Eurajoki, a road leads to Olkiluodontie via Linnamaa. The Olkiluoto area has efficient transport connections with ports, roads and parking areas.

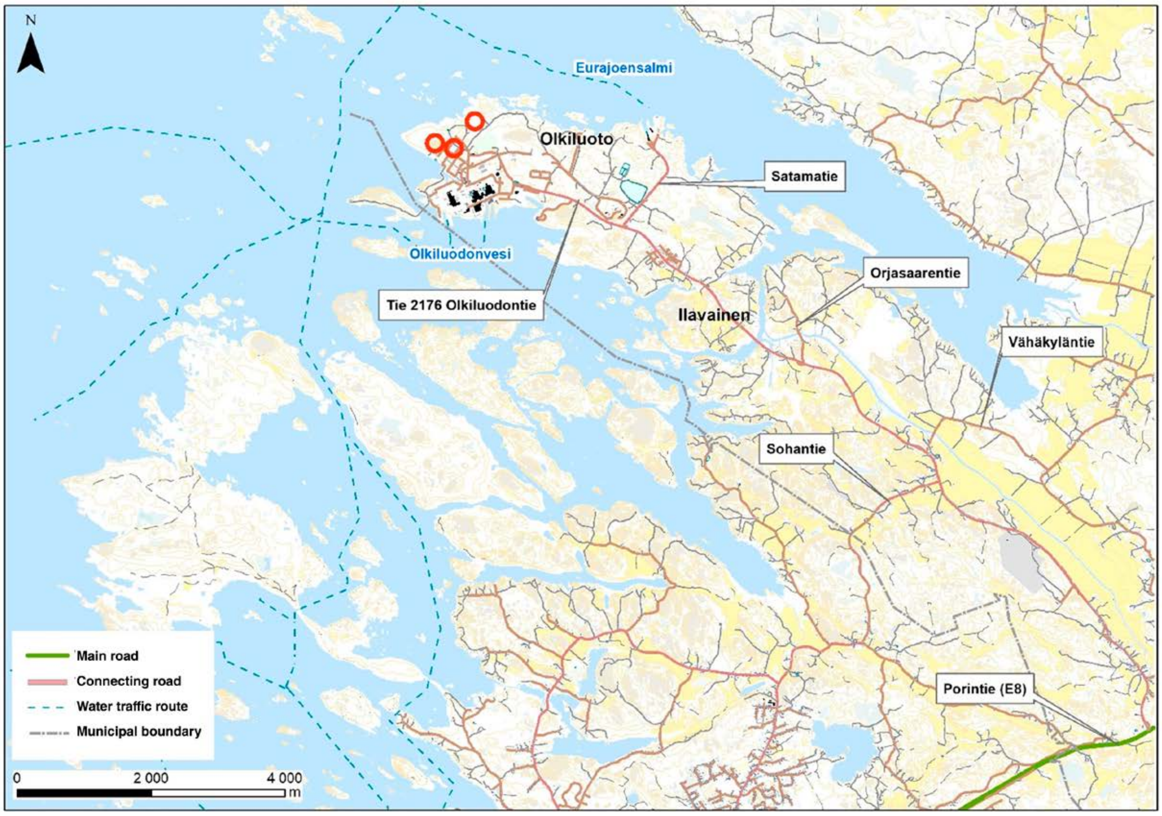


Figure 6-1. Roads in the vicinity of the final disposal area.

Olkiluoto's traffic volumes fluctuate very widely due to large construction projects (OL3 and ONKALO) and the annual outages of the nuclear power plants. The busiest section of Olkiluodontie is around one kilometre from the junction of national road 8 in the direction of Olkiluoto. In 2020, the average daily traffic on Olkiluodontie was 3,185 vehicles per day, of which there were around 159 heavy vehicles per day (Finnish Transport Infrastructure Agency 2020). The largest share of traffic is commuting. The average daily traffic in the national road 8 junction was 10,595 vehicles, of which approximately 1,262 were heavy traffic (Finnish Transport Infrastructure Agency 2020).

Olkiluodontie has a light traffic route up to Hankkila, and a sensitive location along the road is the Lapijoki school at the beginning of the road.

Traffic safety

Based on traffic accident statistics (road 2176 and national road 8), there has been an average of about 5 accidents per year on both road sections in 2015–2019, and the most common type has been accidents with deer. Accident statistics on the entire road section have been reported for road 2176, and on the section of the Olkiluodontie junction for national road 8. There have also been rear-end collisions and head-on collisions. A total of 11 collisions during the above mentioned period have resulted in personal injury. No fatal collisions have occurred.

During the construction phase, an increased amount of heavy traffic will occur, which will impair traffic safety on transport routes especially in the vicinity of the project area. The heavy traffic also affects perceived safety.

The impact on accident rates of an increase in traffic volumes can be assessed using the probabilities of accidents occurring. Generally, accident risk is spoken of, which can be defined as the ratio of accidents on a road section to the risk of exposure of people moving on the road section, typically traffic volumes. If no measures are taken to improve road safety as the volume of traffic increases, the number of accidents can also be expected to increase in the same proportion. Estimated in this way, the number of traffic accidents will increase on the road sections examined (road 2176 and national road 8) by an average of less than 1 per year, taking into account heavy traffic. However, it must be kept in mind that in practice, heavy traffic during construction is due to take place over a period of a few months, which also increases the risk of accidents in the short term.

Along Olkiluodontie there are industrial activities and sparsely populated areas. Olkiluodontie has a light traffic route up to Hankkila, and a sensitive location along the road is the Lapijoki school at the beginning of the road. However, transports and traffic during construction are not expected to pose a particular risk to the above locations. The traffic load caused by the final disposal of spent nuclear fuel is significantly lower than the load of heavy traffic caused in previous years in connection with the construction of the Olkiluoto nuclear power plants.

6.1.2.1 IMPACTS OF SPENT NUCLEAR FUEL TRANSPORTS AND THE RELATED RISKS

The risk review for spent nuclear fuel transports is included as Appendix 12 to the operating licence application, "*Analysis of the risks related to the transport of spent nuclear fuel*".

6.2 LAND USE, CULTURAL HERITAGE, LANDSCAPE, BUILDINGS AND STRUCTURES

6.2.1 ASSESSMENT METHODS

The project's impacts on the current and planned land use, landscape and built environment have been assessed with regard to the land use plans and development.

The landscape impacts have been assessed based on the project plans, existing reports, terrain visits, and reviews of maps and aerial photographs. The landscape impacts are caused by the overground structures of the encapsulation plant and disposal facility and their related functions. The impact assessment describes the characteristics of the environment near the final disposal site as well as valuable landscape and cultural environment sites. Furthermore, the assessment has examined whether the final disposal area will change the character of the sites' landscape, from which directions the view towards the disposal facility area will undergo significant changes and whether there will be significant impacts on the valuable landscape

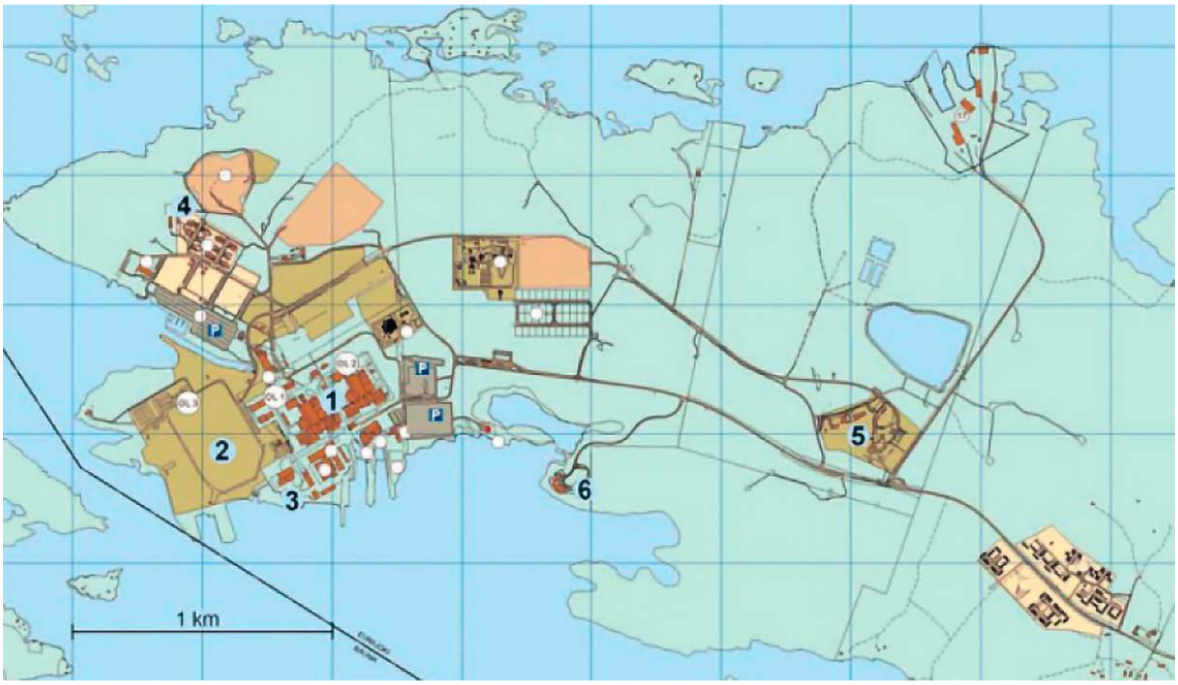


Figure 6-2. Olkiluoto. The map shows the Olkiluoto 1 and 2 (1), Olkiluoto 3 construction site (2), KPA storage (3), VLJ cave (4), Posiva's Onkalo construction site (5) and visitor centre (6).

Figure 6-3. Olkiluoto area in summer 2021. TVO's nuclear power plant units, Olkiluoto 1, 2 and 3, are shown at the top of the figure. The buildings in the middle of the figure are part of Posiva's encapsula-tion plant and disposal facility. To the right of the buildings, there is the Korvensuo basin.

and cultural environment sites. In particular, the assessment has examined the impacts on the residential and recreation areas located near the encapsulation plant and disposal facility.

6.2.2 CURRENT STATE OF THE ENVIRONMENT

The functions located in the surroundings of Olkiluoto and land ownership. The nearest village at Olkiluoto, Hankkila, is located at approximately 8 km from the Olkiluoto disposal facility area. Linnamaa, which is located at approximately 10 km from the disposal facility area, is part of the Vuojoki cultural landscape, which includes the Vuojoki estate and the remains of Liinmaa Castle, which dates back to the 1360s. The Kuivalahti village centre is located north of Eurajoensalmi at approximately 9 km from the disposal facility area, and the Lapijoki village centre is located along national road 8 at approximately 14 km from the disposal facility area. In Rauma, the nearest village centre is Sorkka, which is located some 9 km southeast from the disposal facility area.

TVO's nuclear power plant area, which covers some 500 hectares, is located on the western side of Olkiluoto Island. TVO's current power plant units, Olkiluoto 1, 2 and 3, are located in the area.

In addition to the nuclear power plant units and the ONKALO construction site, the area features administrative buildings, a multi-activity centre, a visitor centre, storage buildings, workshops, an annual outage building, an auxiliary heating plant, a raw water basin, a raw water purification plant, a debris handling building, a demineralisation plant, a sanitary water purification plant, a landfill, a spent fuel interim storage (KPA storage), interim storages for low and intermediate level power plant waste (the MAJ and KAJ storages), an operating waste repository (VLJ cave), a contractor area and an accommodation village. In addition, a near-surface final disposal facility for very low-level waste (the HMAJ facility) will be built in the area. Furthermore, there is a substation of Fingrid Oyj and a gas turbine power plant jointly owned by Fingrid Oyj and TVO for back-up power needs at Olkiluoto. The functions located at Olkiluoto are shown in the figure (Figure 6-2).

Posiva's spent nuclear fuel final disposal area is located in the centre part of Olkiluoto Island, in the east section of the power plant area. The area covers approximately 36 hectares and it is bordered in the south by a road that runs across the island to the power plants and in the east by a road that runs to the port and dock area. Immediately north of the area there is the Korvensuo basin, through which the water taken from Eurajoki is conveyed to the nuclear power plant for use. Posiva is using a quarry material storage area outside the facility area, where the quarry material generated in the excavation of the Posiva disposal facility is transported. There is an environmental permit valid until further notice for storing and crushing quarry material.

The figure (Figure 6-3) shows the location of the encapsulation plant and disposal facility at Olkiluoto Island. The Olkiluoto nuclear power plant units are shown at the top of the figure.

The structures constructed in the overground section of Posiva's area include the entrance to the underground section of the disposal facility, a project office, field laboratory, various storage and workshop buildings, a firefighting water pump house, ventilation and lifting equipment buildings and the spent nuclear fuel encapsulation plant. Furthermore, in the facility area and its surroundings, research on the bedrock and soil properties, for instance, is carried out. Therefore, connecting roads and protective structures for research holes have been built in the area and its surroundings as well as other structures related to the research activities.

Olkiluoto Island mainly comprises forests east of the power plant area. At the middle section of the island's north shore, there is the Olkiluoto industrial port. At the east end of Olkiluoto Island, there are agricultural areas and holiday residences. The area has an accommodation village and caravan area for the temporary accommodation of the nuclear power plants' construction and service personnel.

TVO owns most of Olkiluoto. In the east section, there are built and unbuilt holiday residence lots in accordance with the local shore master plan and some privately owned individual larger land areas. The government owns the Liiklankari conservation area at Olkiluoto and the west part of the Kornamaa island. The Liiklankari area is governed by Metsähallitus. TVO owns some of the water areas surrounding Olkiluoto entirely and some through joint ownership.

6.2.2.1 STATUS OF LAND USE PLANNING

The status of land use planning is presented in Appendix 3 to the operating licence application, *"Description of settlement and other activities on the nuclear facility site and in its vicinity, including land use planning arrangements".*

6.2.2.2 LANDSCAPE

Olkiluoto Island is located in the municipality of Eurajoki on the coast of the Bothnian Sea. Features typical of the Bothnian Sea coast include capes pointing to northwest, shallow bays between them and archipelago areas covering a small area.

The Olkiluoto area belongs to coastal Satakunta in the regional landscape division. The region is characterised by low-lying terrain and the soil that comprises small features: in addition to outcrops of bedrock, there are till areas, small areas of clay soil and ridge formations. The coast has long, sheltered bays with reeds, which are gradually turning to land as a result of land upheaval at a speed of approximately 6 mm per year.

Olkiluoto Island is approximately 6 km long and 2.5 km wide. The Bothian Sea is located west of the island. The southern side of the island abuts the Rauma archipelago. The Lapinjoki river discharges into a narrow strait east of Olkiluoto Island, between Olkiluoto and Orjasaari. The Eurajoki river discharges into the Eurajoensalmi strait north of the island.

Olkiluoto is an island, and the water areas separating it from the continent are gradually turning to land. The highest points of Olkiluoto are the Liiklankallio clifftop, which reaches to approximately 18 m above sea level and the Selkänummenharju ridge, which reaches to approximately 15 m above sea level. The Olkiluoto landscape can be roughly divided into the following zones:

- inland forest zone,
- coastal forest and bedrock zone,
- residential zone at the southern and eastern shores of the area,
- industrial zone at the western end of the area (power plant area) and the northern shore (dock).

The forest zone is divided by a wide power line corridor and the Olkiluodontie road. The inland forest zone includes functions relating to the operation of the encapsulation plant and disposal facility and the power plant, which are not visible in the distant landscape and road landscape. In the forest zone road landscape, the most prominent element is the accommodation village on both sides of the road.

From the sea, Olkiluoto appears to be primarily a woodland area, and the elements indicating power plant and final disposal operations, such as the power plant buildings with their stacks, ventilation building and power lines, rise high and are visible far in the distant landscape. The industrial port and its cranes are prominently visible in the wooded zone on the northern shore. *(Insinööritoimisto Paavo Ristola Oy & Ramboll Oy 2007a.)*

6.2.2.3 CULTURAL HISTORY

Still in the 1960s, Olkiluoto mainly belonged to the Vuojoki estate. Vuojoki Manor is one of the most significant cultural historical buildings in Satakunta. The central and western parts of Olkiluoto were uninhabited forest terrain where horses from the Vuojoki estate grazed. On the eastern side there were small fisherman's farms with forest pastures and field areas that have remained almost the same size and in agricultural use until now. The actual road to the island was only built in the 1960s. The construction of the first power plant at Olkiluoto started in the 1970s. There are small fishermans's farms on nearby islands. Some of them have been dismantled and some of them have been expanded and renovated to serve as holiday homes. The oldest buildings at Olkiluoto date back to the early 20th century. Most of the residential buildings have been built in the post-war rebuilding period or later. Holiday homes have been constructed since the 1960s and 1970s.

6.2.3 ESTIMATED EFFECTS

6.2.3.1 EFFECTS ON LAND USE

The Olkiluoto area has been used for nuclear power plant operations for more than 40 years, and it has proven to be a well suited location for this purpose. The overground sections of the encapsulation plant and disposal facility are located in the centre part of Olkiluoto Island. The land use in the plant and facility site is consistent with the land use in other parts of Olkiluoto Island, and the plant and facility are supported by the infrastructure built earlier at Olkiluoto. The encapsulation plant and disposal facility can utilise the functions that support the operation of the current nuclear power plant units as well as the facilities and structures built for them. The external infrastructure required by the plant and facility comprises traffic connections. For the most part, this infrastructure already exists due to the construction of ONKALO.

The partial master plan includes reservations for the overground final disposal functions. Furthermore, the partial master plan defines an area for the underground final disposal functions and specifies a protection zone for it. The extent of the area is determined by the occurrence of the bedrock most favourable for final disposal at the final disposal depth. When excavating and drilling the bedrock, it must be taken into account that the area is within the protection zone of the encapsulation plant and disposal facility. Before excavation and drilling of the bedrock, the party carrying out the final disposal activity must be consulted.

The local detailed plan indicates the location and depth of the underground disposal repository and the underground building right of the facilities counted as part of the floor area. In addition, the local detailed plan assigns the building right for the overground construction, i.e. the nuclear facility and its operations. The normal operation of the encapsulation plant and disposal facility, anticipated operational occurrences or possible accidents do not limit land use outside of the overground facility area. In the environment surrounding the nuclear power plant, precautions have been taken in the form of land use and public protection plans, with a view to the possibility of an accident. The necessary preparedness and security arrangements for the encapsulation plant and disposal facility will be based on these arrangements.

In connection with the issuance of the closure permit for the disposal facility, land use restrictions may be applied. The limitations may apply to drilling and excavation activities, for example.

6.2.3.2 EFFECTS ON BUILDINGS, STRUCTURES AND THE LANDSCAPE

In addition to the encapsulation plant, there are facilities overground for auxiliary and ancillary functions. These include, for example, shaft buildings; office and laboratory facilities; warehouse and workshop facilities; and facilities required by HPAC and electrical systems. Separate areas will be reserved for the storage of quarry material and crushed rock and for the necessary work site activities. From the ground surface to the disposal repository, there is a driving tunnel and the necessary number of vertical shafts for ventilation, personnel traffic and canister transfers. The overground construction area of the plant site, i.e. the floor area of buildings, roads, warehouses and fields, totals approximately 20 hectares.

In the excavations in the plant area, the district heating pipelines and the pipeline network for domestic water run mainly along road lines. Other pipeline networks include the basic water drainage pipeline network and the rainwater drainage network. The cables will have their own trenches built.

The buildings implemented on the plant site are shown in the figure (Figure 3-2). The encapsulation plant is the most important of these. The encapsulation plant is approximately 72 metres long and 42 metres wide. The lowest floor level of the building is around -2.9 metres, the highest +26.1 metres and the ground floor around +10.3 metres. The volume of the building is approximately 73,000 m3 and the surface area approximatelyn 3,100 m2. The encapsulation plant is separated from the rest of the plant area by a plant fence. The figure (Figure 6-3) shows a view of Olkiluoto Island. In the middle of the island is a quarry material dumping area. The encapsulation plant and disposal facility will have minor impacts on the landscape.

6.2.3.3 EFFECTS ON CULTURAL HERITAGE

The area has no buildings that would have national or local cultural-historical value, significant constructed cultural environments or other such sites (*Ympäristöhallinnon karttapalvelu 2012* and the Finnish Heritage Agency 2007). No antiquities have been found in the Olkiluoto area *(Insinööritoimisto Paavo Ristola Oy & Ramboll Oy 2007a).*

6.3 SOIL, BEDROCK AND GROUNDWATER

6.3.1 ASSESSMENT METHODS

The impacts of the project on the soil and bedrock of the plant area have been assessed using the geography of the area; the quality of the soil and bedrock; and the extent of the area and underground sections needed by the encapsulation plant and disposal facility and related structures. The effects on the bedrock of heat generation by spent nu-clear fuel have been assessed.

In order to plan the final disposal of spent nuclear fuel, a large amount of research has been and is being carried out at Olkiluoto, such as re-search excavations, drilling, geophysical surveys, groundwater flow measurements and groundwater composition studies. The studies inves-tigate the properties of rock and the flow paths of groundwater. In addi-tion, since the start of the construction of ONKALO, information has been collected on the properties of the bedrock, for example through borehole surveys and systematic mapping of the rock surfaces in the tunnel. The accumulated extensive observation and measurement data have been used as a basis for modelling that has formed a comprehen-sive picture of the Olkiluoto bedrock and its groundwater conditions *(Posiva. 2021. Olkiluoto Site Description 2018. Posiva-raportti 2021-10.).*

In order to assess the effects on groundwater, the location of the final disposal area in relation to the groundwater areas and the potential risks to groundwater from construction and operation – such as groundwater level depletion and changes in groundwater chemical composition – have been investigated. The assessment is based on existing surveys, calculations and studies. The amount of groundwater leaking into un-derground rock spaces (total leakage) has been measured for the driving tunnel and shafts.

The effects of the construction of ONKALO are tracked in the Olkiluo-to monitoring programme by measuring and monitoring numerous pa-rameters related to hydrology and hydrogeology, hydrogeochemistry, the environment and rock mechanics *(Posiva. 2021. Olkiluodon Monitorointiohjelma - 2022. Posiva-raportti*

2020-02.). Among other things, the hydrology and hydrogeology follow-up programme in-cludes groundwater level, groundwater pressure height, open hole flow conditions, groundwater flow (cross-flow of holes), water conductivity, groundwater salinity and electrical conductivity, precipitation (includ-ing snow), sea level, surface runoff, seepage, frost, leaking water in tunnels, the water balance of the tunnel system and the water balance of the Korvensuo basin. Precipitation, frost and surface runoff are reported annually in an annual report on the monitoring of the surface environ-ment.

Hydrogeochemical monitoring focuses on the study of the qualities and origin of groundwater as well as possible chemical changes in it. The follow-up programme for rock mechanics includes, among other things, the monitoring of micro-earthquakes and bedrock movements. The models are updated based on the new information collected.

The amount and use of contaminants in the disposal repository are monitored through the Group's TLTA (safety-classified materials) pro-cess. Only contaminants licenced through the TLTA process can be used in the disposal repository.

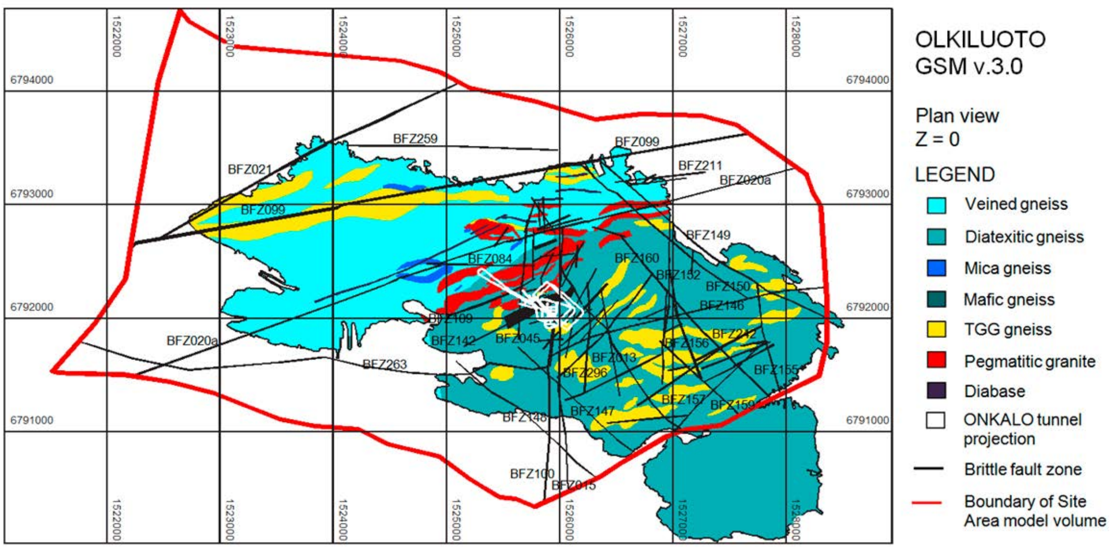
6.3.2 CURRENT STATUS OF THE SOIL, BEDROCK AND GROUNDWATER IN THE AREA

6.3.2.1 SOIL AND BEDROCK

The main bedrock mineral at Olkiluoto is migmatite, which is a compound of mica gneiss and granite. The bedrock in the area is around 1,800 to 1,900 million years old *(Aaltonen, I. (ed.), Engström, J., Front, K., Gehör, S., Kosunen, P., Kärki, A., Paananen, M., Paulamäki, S., Mattila, J. 2016. Geology of Olkiluoto. Posiva-raportti 2016-16.).*

Studies have shown that the surface of the rock up to a depth of around 120–140 m is more cracked than the rock at a deeper depth. In addition, cracks in rock surface sections are more often water-conducting than the deeper rock.

The island of Olkiluoto is quite flat, and there are no major elevation differences. On average, the ground surface is five metres above sea level. The highest point of the island (Liiklankallio) is approximately 18 metres above sea level. The height of the bedrock surface varies, but the moraine smoothes the terrain. The depressions have thick layers of moraine, while at the highest points the bedrock is exposed or covered by only a thin layer of earth. *(Lahdenperä et al. 2005.)* Land upheaval, around six millimetres a year (Eronen et al. 1995), combined with shallowness, has kept the nature of the island in a state of change, and changes still continue to occur in both vegetation and soil. The sea areas near the island are mostly shallow, so the area of the island is growing relatively rapidly, and the island will eventually connect to the mainland. The bottom of the sea



■ **Figure** 6-4. Bedrock rock types and fracture structures interpreted in the Olkiluoto Island area.

area immediately surrounding Olkiluoto is mostly rock, clay and moraine. (*Rantataro 2001.)*

As the island of Olkiluoto has risen from the sea during the last 3,000 years, its soil is mainly young and still at the beginning of its development. Both its youth and the proximity to the sea are reflected in the characteristics of the land and groundwater. *(Haapanen et al. 2007.)* The predominant soil type is finely grained moraine. However, there is considerable rockiness. In coniferous forest, the organic layer is typically raw humus or peat soil. *(Tamminen et al. 2007.)*

6.3.2.2 MODELLING OF OLKILUOTO

After the decision-in-principle (2001), an Olkiluoto site description was published in the report Olkiluoto Site Description 2004 *(Posiva 2005*). Before the site description in the construction licence application in 2011 *(Posiva 2012b*), the site description was also updated in 2004 *(Posiva 2005)*, 2006 *(Andersson et al. 2007)* and 2008 *(Posiva 2009)*. The Olkiluoto geological site model was updated in 2016 in the report Geology of Olkiluoto (Aaltonen et al. 2016). The surface sections of the structures interpreted in the Olkiluoto Island area are shown in the figure (Figure 6-4). The hydrogeological modelling of Olkiluoto and its development is presented in the report Hydrogeology of Olkiluoto (Posiva 2021), and the site description of rock mechanics in the report Rock Mechanics of Olkiluoto *(Posiva 2021).* The hydrogeochemical model and the latest summary prepared of the surface environment properties and bedrock site models are presented in the Olkiluoto site description report (Olkiluoto Site Description 2018) prepared for the operating licence application.

6.3.2.3 SURFACE HYDROLOGICAL MODEL OF OLKILUOTO

The hydrogeological model of surface water and rock groundwater at Olkiluoto (the so-called SHYD model) includes both unsaturated and saturated water flow in the soil layer, connecting the flow in the surface part to the flow of rock groundwater. Among other things, the initial data for the modelling include the ditch network of Olkiluoto Island (Figure 6-5), land use and vegetation data, hydrological measurement data on the soil layer and properties related to the rock groundwater flow. Relevant data describing the hydrological properties of the soil layer include the water retention properties of the soil and the water conductivity of the unsaturated soil.

The ditches on Olkiluoto Island are forest ditches, roadside ditches or agricultural drainage ditches that transport the waters of the catchment areas to the sea surrounding the island. According to the modelling results, the annual surface runoff represents around 17% and evapotranspiration 66% of the precipitation *(Posiva 2019-02).* The model was also used to estimate the amount

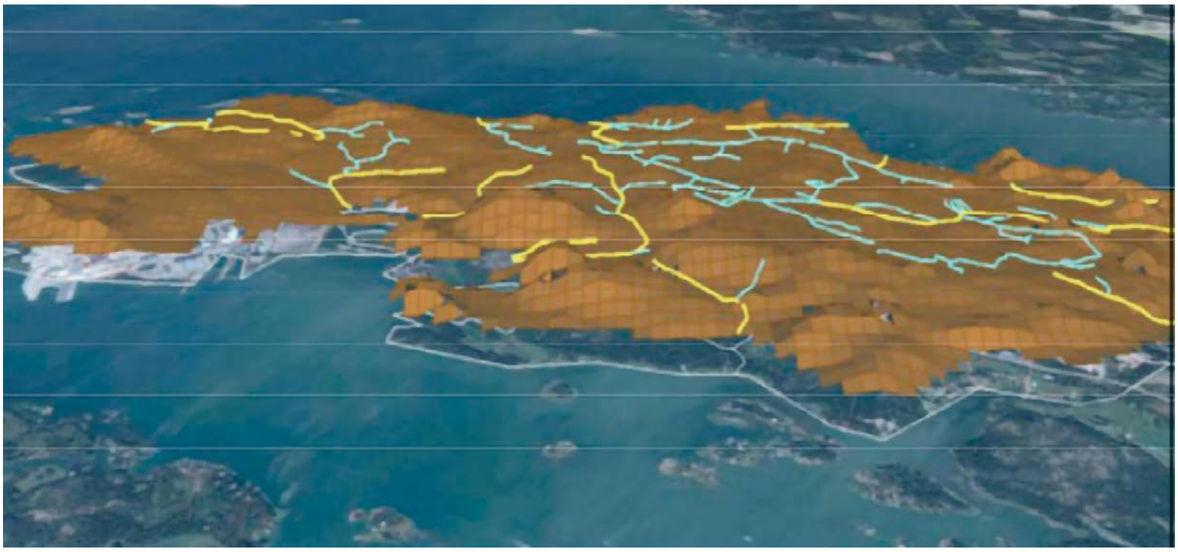


Figure 6-5. The terrain height (exaggerated) and ditch network on Olkiluoto Island.

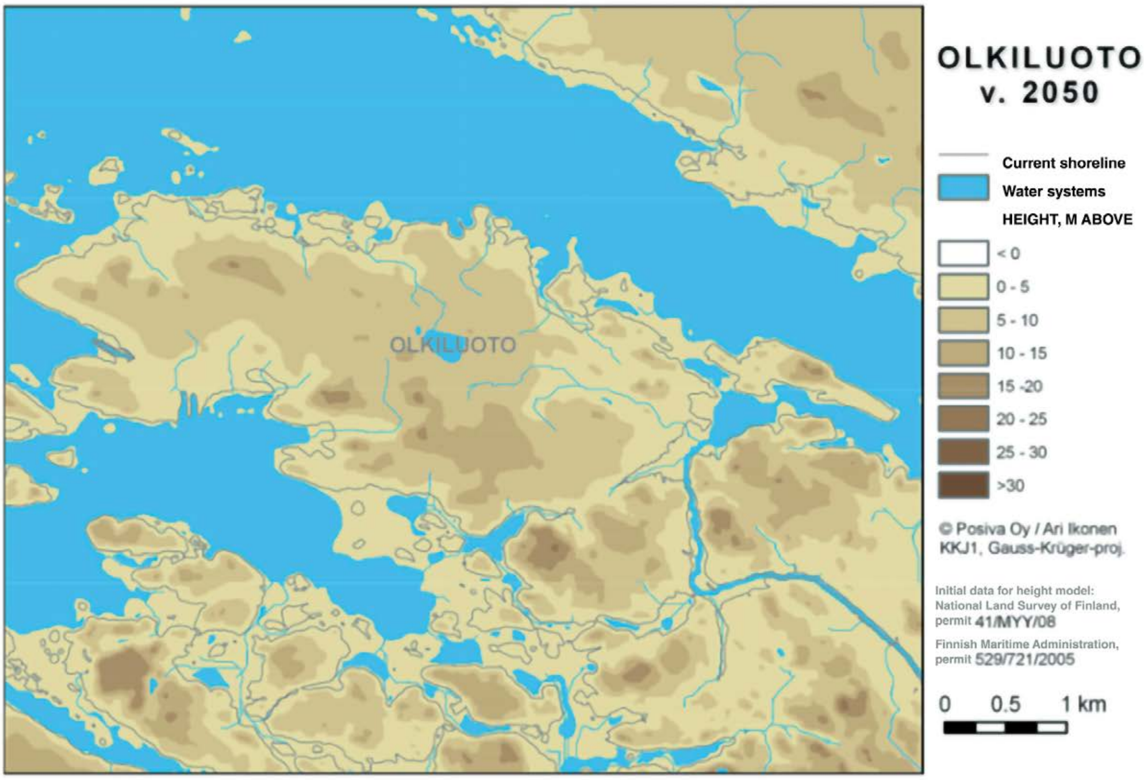


Figure 6-6. The topography of Olkiluoto in the 2050s.

of water that seeps into rock groundwater. According to the results, the amount of water that seeps through the surface is approximately 405 mm per year, and the amount of water that flows to a depth of more than 50 m per year to become deep groundwater is approximately 5 mm per year *(Posiva 2019-02).* The modellings also took into account the possible impact of the Korvensuo basin and ONKALO on the flow conditions *(Karvonen 2010, Posiva 2019-02).*

6.3.2.4 LAND UPHEAVAL

There will be no significant effects of land upheaval in the Olkiluoto area over the next hundred years. Munakari will become part of Olkiluoto, and a lake or wetland will form at the current strait separating them (Figure 6-6). Olkiluoto will become connected to the mainland when the narrow strait that separates the two dries up.

6.3.2.5 SEISMOLOGY

The Baltic Shield, and especially the Precambrian bedrock of Finland belonging to it, is one of the most seismically stable geological regions in the world.

Current seismic activity at the Olkiluoto plant site has been monitored by the macroseismic monitoring network maintained by the Institute of Seismology of the University of Helsinki, and since 2002 also by Posiva Oy's microseismic monitoring network. The results of the seismic monitoring network maintained by Posiva Oy are published annually. The monitoring results of the seismic network for 2019 are presented in the report Haapalehto et al. (2020).

No macroseismic events have been observed on Olkiluoto Island during the entire period of this seismic monitoring (Saari 2003; Ahjos & Uski 1992; ISUH 2019a & 2019b). All known macroseismic events at a distance of less than 100 km from Olkiluoto have been small (M < 3.1), and based on existing earthquake catalogues containing historical observations, 17 natural earthquakes at a distance of 100 km have been identified between 1804 and 2018 (Figure 6-7). At a distance of less than 50 km from Olkiluoto, 6 earthquakes have been identified in the same timespan (Figure 6-7), the closest of which occurred in Eurajoki on 29 September 2008, but at a small magnitude, ML = 0.8 (Figure 6-9). Prior to the installation of the monitoring network, based on historical data, an earthquake was identified to have occurred in 1926 in the Uusikaupunki area, the magnitude of which has been estimated at M = 3.1 (Figure 6-7). Based on

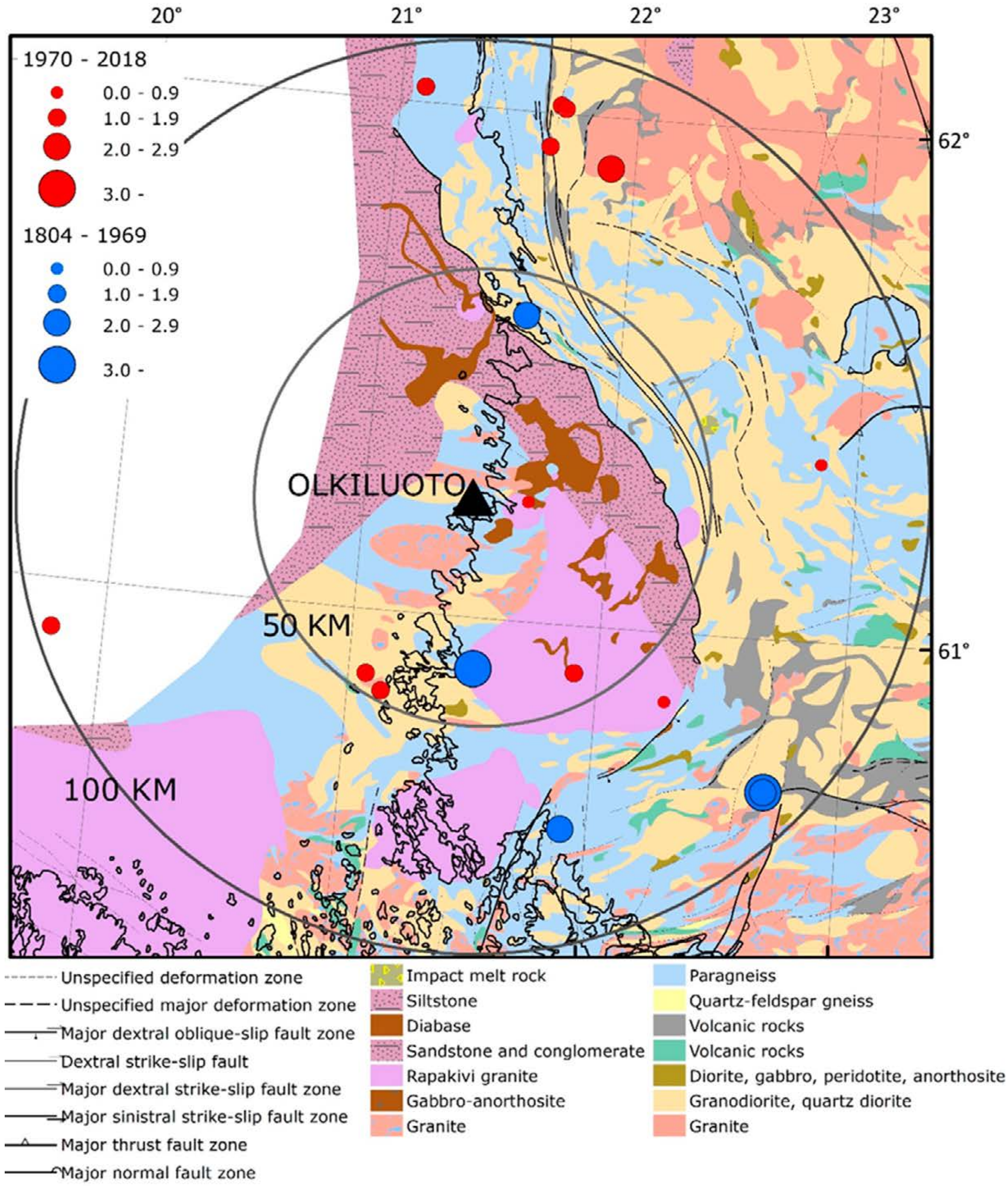


Figure 6-7. Natural earthquakes identified on the geological map of Satakunta within a radius of 100 km and 50 km from the Olkiluoto plant site. Red circles represent earthquakes detected by the monitoring network, and blue circles represent historical earthquakes before the installation of the seismic monitoring network. The figure was produced by Outi Kaisko, and the data are based on Ahjos & Uski 1992, ISUH 2019a and ISUH 2019b.

historical and monitored observations, as well as Posiva Oy's continuous monitoring data, natural seismic activity in the Olkiluoto area is low.

6.3.2.6 GROUNDWATER

The groundwater level loosely follows the topography of the ground; in moraine-covered areas, groundwater is typically at a depth of 1–2 m, and on the shore, the groundwater level coincides with that of seawater. There are no classified groundwater areas at Olkiluoto, and the area is not significant for the procurement of water for communities. There are a few privately owned boreholes on the island that are either in continuous or leisure-time use. The nearest classified groundwater area is located in Kuivalahti, north of Eurajoensalmi, approximately six kilometres northeast of the encapsulation plant and disposal facility.

In the basic state, the groundwater of the Olkiluoto bedrock is divided into layers that differ in things such as salt content and anion composition. Based on the differences in concentrations, groundwater is divided into basic-state groundwater types (HCO3, SO4 and Cl water types) and mixtures of these *(Pitkänen et al. 202X)*. Groundwater is fresh for the first ten metres (salinity less than 1 g/l), below which there is brackish water up to a depth of around 400 metres (salinity 1–10 g/l). At the final disposal depth (–420 m), the water is either brackish water or saline groundwater (maximum 21 g/l). The salinity continues to increase as the depth increases. The highest salinity (130 g/l) measured at Olkiluoto was measured in 2015 in a water sample taken from borehole OL-KR1 at a depth of –902 m (Lamminmäki et al. 2017a).

Groundwater flows in bedrock fissures and fracture zones. A hydrogeological structure model is maintained for the known water-conducting zones of the Olkiluoto bedrock *(HZ model, Vaittinen et al. 2020a).* Information on the groundwater layers, flow conditions and flow paths of the bedrock is obtained by monitoring the pressure height of deep boreholes, flow measurements and water sampling. Typically, the water conductivities of the fissures are greatest in the upper parts of the rock and decrease with increasing depth. Among the most significant water-conducting structures at Olkiluoto are HZ19A-C and HZ20A-B.

The construction of underground facilities affects the flow paths and velocities of water moving in the bedrock of Olkiluoto, and thus also the hydrogeochemical properties of the water when different groundwater types mix. These changes are monitored annually in the Olkiluoto monitoring programme, the results of which are presented in annual reports. The latest monitoring reports cover the results for 2019 *(Yli-Kaila et al. 2020, Vaittinen et al. 2020b).*

6.3.3 IMPACTS ON SOIL, BEDROCK AND GROUNDWATER

6.3.3.1 OVERGROUND STRUCTURES

The overground rock excavations related to final disposal operations have already been completed. These surface excavations have been car-ried out mainly for the construction of buildings, roads and yards in the area. The required overground buildings have been constructed already before the start of final disposal.

6.3.3.2 IMPACT OF THE UNDERGROUND DISPOSAL FACILITY ON THE BEDROCK

The surface area required for the underground facility section is approximately 150 hectares for the final disposal of 6,500 tU of fuel. The combined length of the deposition tunnels is approximately 35 km.

With the exception of the deposition holes and shafts, excavation work for the disposal repository has been carried out using the drilling-blasting method; as technology advances, mechanical excavation may also be considered in the future. In excavation, special attention has been paid to the excavation quality and the impact of excavation on the rock surrounding the tunnels. The allowed overexcavation tolerance is kept small so as not to unnecessarily increase the volume to be filled later. When excavating tunnels, the bottom of the tunnel can be excavated separately, which means that the effect on the rock of the floor and the lower parts of the walls is smaller.

The drilling-blasting method used in excavation consists of several different intermediate steps. The excavation holes needed to remove one gap are first drilled at the end of the tunnel. In the next step the holes are charged, and after charging the gap is blown up and the tunnel is ventilated. The blasted quarry material is loaded onto vehicles and transported through the driving tunnel to the ground surface. After emptying the end to be excavated, the drilling of new excavation holes is started again. If necessary, injection and reinforcement work is carried out between the different phases. The excavation work may be interrupted by various surveys and studies. The deposition holes in the floor of the deposition tunnels are drilled using a purpose-developed drilling method. Material generated through drilling is removed from the bottom of the hole by means of a vacuum air purge. The equipment can be used to drill large diameter holes from top to bottom in a low deposition tunnel. Most of the technical construction work for the disposal repository will be carried out during the construction phase of ONKALO, including the structures of the driving tunnel, the person shaft, air supply and exhaust air shafts and the technical facilities of the non-controlled area.

The construction work to be carried out in the construction phase prior to final disposal include the construction of the premises in the radiation controlled area, the canister shaft, the central tunnels and the first deposition tunnels. During the operating phase, construction work will be carried out in the central and deposition tunnels in connection with excavation work to be carried out approximately every 5 to 10 years.

6.3.3.3 THE EFFECTS OF HEAT GENERATION ON THE BEDROCK

The heat generated in each canister raises the temperature in the vicinity. For this reason, each batch of spent fuel removed from the reactor must be cooled so that the temperature of the bentonite around the canisters does not exceed +100 °C during final disposal. If the temperature in the vicinity of the canisters were to become too high, chemical changes might occur in the bentonite buffer which would impair its protective properties. The total heat output of the disposal repository is more or less directly proportional to the number of waste canisters in the disposal repository. However, the temperature in the vicinity of the canisters is not particularly sensitive to the total number of canisters placed in the disposal repository, as the canisters are placed separately according to thermal sizing in order to avoid excessive temperature rises. The residual heat of the spent nuclear fuel will cause thermal expansion of the bedrock. Using the element method and analytically, the surface of the earth has been calculated to rise by a maximum of around seven centimetres in the middle of the disposal repository due to thermal expansion over a period of more than a thousand years. *(Ikonen 2007.)*

6.3.3.4 AMOUNT OF QUARRY AND OTHER ROCK MATERIAL GENERATED

For a fuel volume of 6,500 tU, the total volume of the underground disposal facility is approximately 1,250,000 m^3, of which around 40% or 500,000 m^3 is the actual disposal repository. Approximately half of the total volume of the disposal facility has already been excavated. In the future, approximately 10,000 to 20,000 solid cubic metres of quarry material will be generated per year, depending on the timing of the quarrying work.

The rock material brought up from the underground disposal repository is stored in a quarry material dumping area at Olkiluoto. It can be crushed if required. The development of construction aims at making the tunnels later by mechanical excavation methods. The crushed rock material thus formed is transported to the surface in the same way as quarry material and dumped.

This rock material will be primarily used for other applications at Olkiluoto either as filler material as is or as crushed and/or screened rock material. One alternative is to sell the rock material obtained from the tunnel to an external party either as is or crushed.

In addition to quarried materials, small amounts of other excavation masses are generated. Excavated earth masses unfit for construction in the project will be stored in the current Olkiluoto dumping area.

6.3.3.5 EFFECTS ON GROUNDWATER

The construction of underground facilities affects the flow paths and velocities of water moving in the bedrock of Olkiluoto, and thus also the chemical composition of the groundwater. Changes are detected by using a monitoring programme during the operation of the disposal facility (*Posiva 2021a).* The figure (Figure 6-8) shows the location of groundwater pipes and shallow rock hole monitoring points at Olkiluoto. In addition, groundwater is monitored from deep boreholes, a total of 58 of which have been drilled at Olkiluoto, and from measuring points located in underground facilities.

When tunnels are being built and the disposal repositories are being used, groundwater leaks into open tunnels, from where it is pumped to the ground surface. This reduces groundwater pressure height around the tunnel system, and the leak volumes may also cause the groundwater level to decrease in the Olkiluoto Island area. The volume of leaking water and the extent of its impact are controlled by sealing the rock around the tunnels as work progresses.

The total leakage from ONKALO is approximately 30 litres per minute (Vaittinen et al. 2020b). According to estimates, the total leakage will be a maximum of around 60 l per minute, depending on how many open disposal repositories are open at a time in addition to the ONKALO driving tunnel. The increase in leaking water as construction progresses is unlikely to increase the very small impact already observed on the groundwater level (less than 0.5 metres above ONKALO), as the parts of ONKALO near the surface have already been built. Locally, the decrease may have been and may continue to be greater in the future at points where better-than-average water-conducting structures are located near the surface and from which water flows into ONKALO. In the current numerical flow models, it is assumed that the groundwater level will not change as a result of the construction of ONKALO.

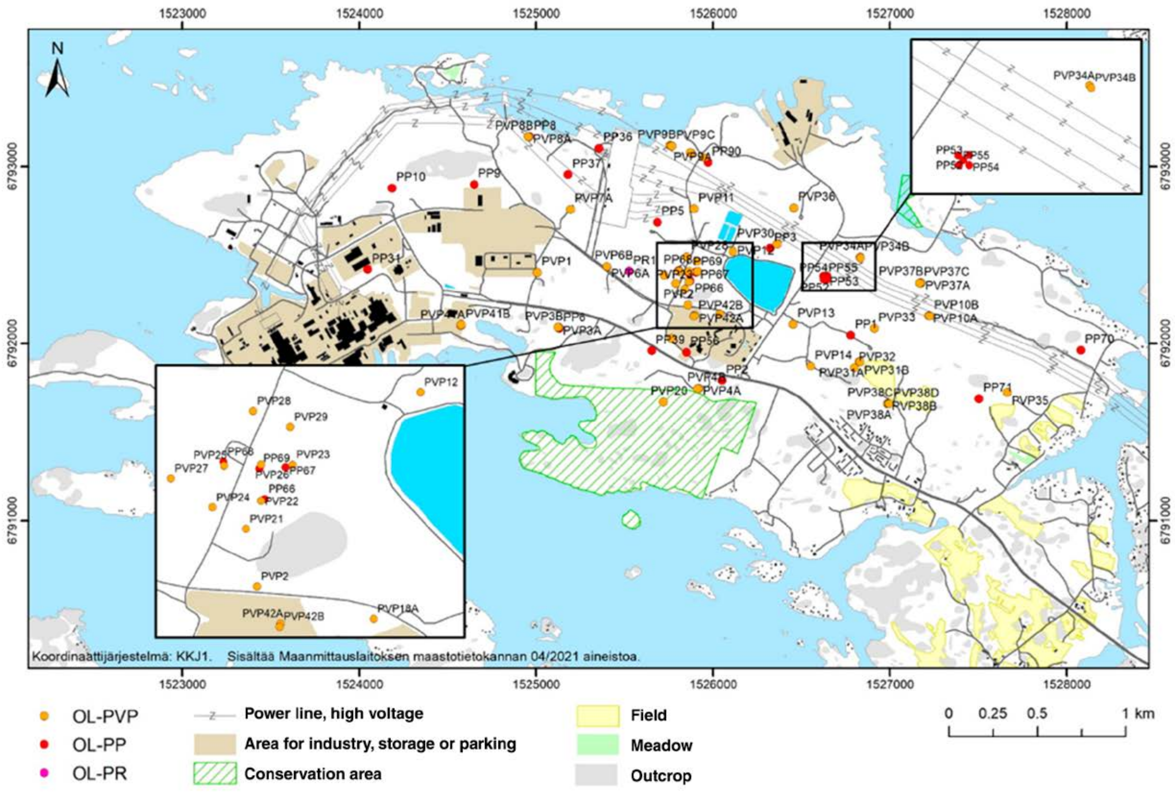
Both short-term and long-term changes in groundwater pressure heights have been observed. Short-term changes have been caused by several different research measures both in the study area and in ONKALO, and by temporary leaks in ONKALO, as the holes made have intersected the water-conducting zones and fissures. In some water-conducting bedrock zones intersecting the tunnels, groundwater pressure heights have stabilised due to steady leakage at a level where the decrease near ONKALO varies from around one metre (HZ19 zones) to well over 10 metres (HZ20 zones) (Vaittinen et al. 2020b). In the vicinity of ONKALO (at a distance of less than 100 metres) the pressure height has decreased in places by more than 100 metres in individual fissures or very local zones, although their intersection in ONKALO leaks less than 1 dl per minute. This is because these fissures have very low water conductivity and do not receive replacement water from their environment. Hydraulic connections between different boreholes and underground spaces, as well as between different boreholes, have been observed by monitoring changes in deep borehole pressure heights and flow conditions. The hydrogeological structure model (Vaittinen et al. 2020a) is updated based on observations.

The changes observed in shallow groundwater chemistry are due to causes such as natural annual variation in hydrological conditions or to seasonal variation, which is typically observed in some shallow groundwater sampling points *(e.g. Yli-Kaila et al. 2020).* Soil thickness and quality also affect shallow groundwater chemistry. An increase in salinity due to the salting of Olkiluodontie has been observed in the OL-PVP4A and OL-PP2 groundwater pipes south of Olkiluodontie since 2006. Land use has had local effects on the composition of shallow groundwater. Elevated concentrations of sulphate, nitrate and nitrite have been observed in the OL-PVP42A and OL-PVP42B groundwater pipes at the encapsulation plant site; these originate from crushed rock excavated from ONKALO *(e.g. Yli-Kaila et al. 2020).* Sulphate dissolved from crushed rock has also been detected at a few observation points in the upper part of ONKALO, for example at groundwater station ONK-KR1. The infiltration of water from the Korvensuo basin in the area into the surroundings has been seen at shallow groundwater sampling sites north of the basin and in a few deep groundwater samples *(e.g. Yli-Kaila et al. 2020, Pitkänen et al. 202X).*

The changes seen in the deeper groundwater of the rock have been most significant in the large, gently sloping zones HZ19A-C and HZ20A-B intersecting the ONKALO driving tunnel (Pitkänen et al. 202X). Dilute water has mixed with the original groundwater of these structures due to the hydraulic pressure gradient caused by ONKALO, and in some cases the open boreholes have also intensified this effect. Dilution has been highest in the vicinity of ONKALO. Changes observed further from ONKALO are mainly due to the mixing of water during an open research hole (borehole). The open borehole forms a hydraulic connection between the different structures, allowing the groundwater to flow from the higher pressure zone to the lower pressure zone. This is especially true if the connection to ONKALO strengthens the suction *(Pitkänen et al. 202X).* In these kinds of cases, dilute water containing bicarbonate and sulphate has been free to flow deeper into the bedrock. With the installation of plug equipment, recovery has taken place especially at sites further away from ONKALO. Based on observations, at a depth of more than 600 m the chemical conditions have remained stable. The mixing of deep groundwater has no direct environmental impact. The long-term safety effects of the construction of underground facilities are discussed in more detail in Section 8.6.1.1.

In recent decades, microbiological processes and their effect on the chemical composition of groundwater have been studied through various research projects and sampling at Olkiluoto. Based on this research, a microbiological model of Olkiluoto has been prepared *(Tuomi et al. 2020).* As anaerobic conditions are one important design basis for technical release barriers, the zone relevant to the final disposal concept is located immediately on the surface of the rock, where oxygenated groundwater becomes anaerobic. The bedrock of Olkiluoto has a large buffer capacity against oxygen infiltration even over geological periods. Another important transition zone is located at a depth of about 300 m, where SO4-type groundwater becomes Cl-type groundwater. Elevated microbial counts and activity, and consequently elevated levels of dissolved sulfide (HS-) have been observed in this zone *(Tuomi et al. 2020)*. The sulfide content is important for the long-term performance of the final disposal canister.

Although the sulphate reduction process and sulphate reducing bacteria are commonly found in the groundwater of Olkiluoto, the accumulation of HS- is limited, among other things by the limited rate of formation due to the availability of electron acceptors and donors required by the process, as well as precipitation of sulfide with iron, which eventually forms pyrite (a long-term sulfide sink). Due to the limiting factors, the sulfide concentration remains low at baseline, but elevated concentrations are observed especially in situations where groundwater is allowed to mix. In the long run, however, the situation will return to a near-stable state, with limited amounts of energy, carbon and nutrients required for sulphate reduction and a reduction in sulfide levels due to the above factors *(Tuomi et al. 2020).* Modelled future trends in the sulfide concentrations in the groundwater at the site are presented in the report Posiva 2021c.



■ **Figure** 6-8. Groundwater pipes and shallow rock holes at Olkiluoto in 2021 (Posiva 2021a).

6.4 CLIMATE AND AIR QUALITY

6.4.1 ASSESSMENT METHODS

Construction work, work site traffic and separate functions (e.g. rock crushing and quarry material dumping) cause local dusting during operations. Vehicles and machinery generate exhaust gas emissions in the air. These emissions and their effects have been assessed as expert work.

6.4.2 CURRENT STATUS OF THE CLIMATE AND AIR QUALITY

Olkiluoto is located on the coast of the Bothnian Sea in a maritime climate. The maritime climate is characterised by the uniformity of thermal conditions. In the spring, temperatures near the coast are clearly lower than further inland. In autumn the warm sea evens out the temperature differences during the day, and there are few night frosts. Winter in the Satakunta region is mild, as the central part of the Bothnian Sea remains free of ice for nearly the entire winter. The snow cover is usually less than 20 centimetres thick. Frost typically extends to a depth of 10 to 70 centimetres. The length of the growing season has averaged 180 days in recent years. The prevailing wind direction is from the southwest. The annual rainfall at Olkiluoto varies from 400 to 700 millimetres. *(Haapanen 2011.)*

Emissions to air are low in Eurajoki. Emissions from smaller industrial plants and other isolated sources (e.g. detached houses, saunas) have not been estimated. There is no air quality monitoring in Eurajoki. The nearest monitoring point is in Rauma. Air quality is also monitored in the industrial towns of Harjavalta and Pori. Emissions in the Rauma area are low compared to those in Pori and Harjavalta.

6.4.3 EFFECTS ON CLIMATE AND AIR QUALITY

6.4.3.1 IMPACT OF EXCAVATION, CRUSHING AND DUMPING ON AIR QUALITY

Dust released into the air from surface blasting can be detected in the direction of the wind for a few hundred metres *(LT-Konsultit Oy 1998).* There are no significant environmental impacts, considering the duration and timing of the excavation and the size of the affected area. At the start of operations, excavation work on the ground will have been completed. Dust from underground blasts does not have an effect on the ground srface.

During the operation and closure phase, the quarry material is crushed for approximately one month every two years. Quarrying and crushing are not done at night. If mechanical excavation methods are introduced in the future, no separate crushing on the ground will be required.

The dust impact of the mobile crushing plant has been assessed using the guide values set by the Finnish Government and the guidelines of the Finnish Road Administration. The crushing is done during the warm season, and dusting is limited by moistening. In winter, the dust sources are protected by blankets or enclosures. The safety distance is 300 metres. If dusting is limited only when necessary, the safety distance is 500 metres. The protective effect of vegetation has not been taken into account in the safety distances *(LT-Konsultit Oy 1998, Tolppanen 1998).*

The impacts of crushing and dumping are not significant due to the short duration of the functions and the small size of the affected area.

6.4.3.2 EMISSIONS DUE TO VEHICLES

Posiva's environmental impact assessment reports completed in 1999 and 2008 found that the project would lead to a maximum increase of a few per cent in the total road traffic emissions of the plant sites. The traffic generated by the encapsulation plant and disposal facility is not relevant for local air quality. For example, the nitric oxide concentrations are well below the guideline values.

6.5 WATERWAYS

6.5.1 ASSESSMENT METHODS

Water supply arrangements have been described and the effects of water supply on the environment have been assessed on the basis of existing research data; the results of Posiva's and TVO's monitoring programmes; and expert assessments.

The treatment of the effluents generated during the operation of the encapsulation plant and disposal facility and the load caused by these have been assessed in the final safety report. The effects of effluents on the quality of seawater have been assessed on the basis of existing research data; the results of monitoring programmes; and expert assessments.

6.5.2 CURRENT STATUS OF WATERWAYS

Olkiluoto is bounded on the north side by Eurajoensalmi, a strait around 1.5 kilometres wide, and on the south side by Olkiluodonvesi, which is around three kilometres long and 0.7–1.0 kilometres wide. The Eurajoki and Lapinjoki rivers flow to the east and southeast of Olkiluoto. The Rauma archipelago begins south of Olkiluodonvesi. To the west of Olkiluoto is a shallow coastal area with a relatively large number of small islands and islets. The Bothnian Sea is located west of the islet zone. *(Kirkkala & Turkki 2005.)*

Physico-chemical and biological monitoring of the local waters of Olkiluoto has been carried out since the 1970s within the framework of TVO's monitoring programme. The purpose of the monitoring is to determine the effects of the cooling waters of the Olkiluoto power plants on the water quality, usability and biological production of the surrounding sea area.

The water quality and ecological status of the Olkiluoto sea area are affected by the general state of the coastal waters of the Bothnian Sea and the nutrients and other substances carried by the rivers. The increase in water temperature and changes in flow conditions caused by the cooling water of the nuclear power plant units only have a significant effect in the immediate vicinity of the cooling water intake and discharge points. Water quality is also only locally affected by the nutrient load of wastewater discharged with cooling water. *(Haapanen et al. 2009.)*

Based on the water quality monitoring results, the concentrations of nutrients in the sea areas in front of Olkiluoto are typical of the coastal waters of the Bothnian Sea. In the Eurajoensalmi strait in particular, the effect of Eurajoki is reflected in higher concentrations of nutrients and solids and lower salinity. Typical vegetation varies according to the quality of the bottom. Macroalgae such as kelp are predominant on hard soils, and freshwater aquatic plants such as water milfoil and common reed on soft ones *(Posiva 2012-10).*

Studies in accordance with TVO's environmental radiation monitoring programme have measured small amounts of radioactive substances originating from the nuclear power plant from the algae, sedimentation material and mussels, and occasionally also from fish, in front of Olkiluoto. The proportion of natural radioactivity in the samples was significantly higher than that of the power plant-derived activity. *(TVO 2012, Taivainen 2007.)*

There are very few freshwater ecosystems in the Olkiluoto area. The only lake on the island has dried up as a result of drainage. The lake (Korvensuo basin) currently visible on the map of Olkiluoto was made as a raw water basin for the power plant in the 1970s, and it is heavily regulated. TVO and Posiva regularly monitor water quality in the Korvensuo basin *(Sojakka et al. 2019).*

6.5.3 IMPACT ON WATER

6.5.3.1 PROCUREMENT OF WATER

Drilling/excavation, washing and extinguishing water systems have already been built during the research phase of the disposal facility, in connection with the construction of ONKALO, and they have been expanded during the implementation of the disposal facility. The process water network was extended to the technical facilities when equipping the personnel shaft. The drilling/excavation, washing and extinguishing water is taken from the Korvensuo basin after humus filtration. The process water is normal piped water. The water is taken from the Olkiluoto water supply network, the existing capacity of which is sufficient to satisfy the water demand.

The average daily water demand of the disposal repository is estimated at around 25 m^3 and the annual demand at around 9,300 m^3. The daily demand for process water is estimated to be around 6 m^3.

6.5.3.2 HANDLING OF SEWAGE WASTEWATER

The toilet wastewater from the underground disposal facility is collected in a tank of 5 m^3 and transported to the surface by vacuum tanker. The sewage wastewater is discharged to the nearby TVO wastewater treatment plant and does not cause significant environmental impacts.

6.5.3.3 HANDLING OF LEAKING WATER

The purpose of the disposal facility's system for leaking water is to collect the water leaking from the rock and the drilling and washing water into the clarification basin, to clarify the water and to pump the water from the clarification basin to the surface for discharging. The underground collection basin for leaking water and other such waters is located at a level of approximately -430 metres. The volume of the basin is 1,800 m^3. Leaking water and other waters are pumped from the clarification basin to the surface through the personnel shaft *(Saanio et al. 2012).* These waters pumped to the surface are then discharged into an oil separation well and above-ground clarification basins, and from there along a pipe to a ditch leading to the sea.

6.5.3.4 HANDLING OF WASTE-WATER FROM THE ENCAPSULATION PLANT

All washing water used in the controlled area of the encapsulation plant is collected through floor drainage in a closed container and analysed in the laboratory for possible radioactive substances. If radioactive substances are detected, the wastewater from the controlled area will be further transported for treatment in TVO's existing waste treatment systems. All liquid radioactive waste generated at the encapsulation plant is solidified and disposed of in TVO's VLJ cave. Wastewater in which no radioactive substances are detected is discharged into the normal sewerage network of the plant site. The quantities of washing water in the controlled area are very small and do not have a significant impact on the environment.

6.5.3.5 IMPACTS OF EARTH-WORKS ON WATER

Earthworks in the ONKALO area have been completed at the start of operations. The effects on surface waters of works related to final disposal have been monitored as part of a monitoring programme for several years (e.g. Sojakka et al. 2019). The impact of earthworks on surface waters has been assessed using field visits and maps *(LT-Konsultit Oy 1998)*. For Olkiluoto, the terrain assessments have been supplemented by additional calculations using the Olkiluoto surface hydrology model (Karvonen 2019). The Olkiluoto surface water network consists almost exclusively of excavated forest ditches or roadside ditches formed in connection with road construction.

The construction of the facility will change the absorption conditions of surface waters, as water from roofs and paved courtyards (three hectares in total) is discharged into the water system.

The discharge directions of the catchments can be maintained by drum tubes, even if the catchments themselves change. Regardless of the scale of the activities or their location, the facility will not significantly affect surface water flows. The transport of surface runoff due to heavy rainfall to ditches has been calculated using a surface hydrology model, and it is calculated that the changes in the water levels of ditches compared to the current situation will be very brief and will not have an adverse effect. *(Karvonen 2019.)*

In addition to runoff changes in the Olkiluoto area, the impact of earthworks and asphalting at the final disposal site on the nutrient and solids load of surface watercourses and the nearby sea area has been assessed. The effect of earthworks and asphalting on the discharge volumes was obtained by multiplying the water volumes calculated in the surface hydrology model of Olkiluoto by the concentrations estimated on the basis of the research carried out in the water management laboratory of the Helsinki University of Technology *(Kotola & Nurminen 2003).*

The surface watercourses at Olkiluoto are mainly forest or roadside ditches, where the load from the area of the encapsulation plant and disposal facility does not cause significant environmental damage. The water quality and biological production of the Olkiluoto sea area are affected by the general state of the coastal waters of the Bothnian Sea and the nutrients and quantities transported by Eurajoki the (catchment area 1,336 km^2) and Lapinjoki (catchment area 462 km2) rivers. The cooling waters of the nuclear power plant on the island also have an impact. Compared to the above-mentioned sources of loads, the additional load caused by the encapsulation plant and disposal facility on the sea area surrounding Olkiluoto is very small.

6.5.3.6 IMPACT OF EXCAVATION, CRUSHING AND DUMPING ON WATER

The excavation leaves small residues of explosives, such as nitrogen compounds, in the quarry and rock. The chemical properties of the drilling water used in ONKALO and the leaking water and other waters pumped out of it have been monitored. Water samples taken from the sedimentation basin on the ground show a clear increase in nitrite, nitrate and total nitrogen concentrations due to excavation. Due to the concrete used to compact the rock, the pH of the sedimentation basin has typically been high, i.e. the water has been alkaline. However, this has not been estimated to be detrimental to the environment, as based on measurements from the discharge ditch, the pH has been neutralised already over a short distance, even before the water is discharged into the sea. *(Kasa 2011, Sojakka et al. 2020.)*

The rock material brought up from the underground disposal repository is stored in a quarry material dumping area. The runoff from the dumping area will be collected in open ditches and further discharged into the sea. The runoff from the crushed rock piles has been regularly monitored during the research phase, in connection with the construction of ONKALO. Monitoring will continue during the construction and operating phases of the disposal facility. In the observations made, the solids concentrations in the runoff water have typically been below 20 mg/l *(Sojakka et al. 2020),* when the average concentration in the application for an environmental permit for storage of quarry has been estimated at about 50 mg/l. The runoff water does not have a significant impact on water quality.

Based on the findings of the monitoring programme, excavation-related crushing and dumping have been found to have an impact on the chemical composition of surface waters and the surface part of the bedrock, as well as that of the groundwater contained in the soil during the construction phase of the disposal facility. ONKALO quarry has been used in the area works, the sulfide minerals of which have oxidised and released some sulphate into the groundwater and surface water of the area as a result of crushing and exposure to water and oxygen, lowering the pH of the groundwater *(Pere et al. 2017 & Lamminmäki et al. 2017b).* The findings are not worrying from an environmental point of view, but the development of the phenomenon needs to be monitored from a long-term safety perspective.

6.5.3.7 IMPACTS OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY ON DOMESTIC WATER AND BOREHOLES

The groundwater situation on the island of Olkiluoto is constantly monitored through a dense observation network. As part of this observation work, some domestic water wells on Olkiluoto Island are monitored regularly. The monitoring provides a good understanding of the effects of final disposal operations on the groundwater conditions on the island of Olkiluoto. In addition, the impact of Posiva's operations and ONKALO on the lowering of the groundwater level is limited to the construction site and its immediate vicinity. So far, the biggest impact on groundwater level has been from the construction work on the ground, instead of the tunnel. The impact on groundwater level depletion is very small. The water level of the wells monitored follows the water level of the reference wells, and no unexplained changes or effects due to the construction of ONKALO have been observed *(e.g. Sojakka et al. 2020).*

The environmental risks to domestic water from the canisters and their contents have also been assessed (*Raiko & Nordman 1999).* The concentrations of the elements relevant to the environmental impact in the well water have been conservatively estimated, assuming among other things that the capsule will completely lose its tightness after 10,000 years. The calculations show that the values are clearly below the concentration limits set for domestic water.

6.5.3.8 EFFECT OF THE ENCAPSULATION PLANT AND DISPOSAL FACILITY ON PUBLIC SWIMMING BEACHES

The public swimming beaches in the vicinity of the encapsulation plant and disposal facility are shown in the figure (Figure 6-16). Based on the results of the monitoring programme, the activities in the ONKALO area and the effluents of the underground facilities have not been found to have an impact on the quality of seawater, and thus on the water quality of public beaches. During the operating phase, the activities do not change significantly from the point of view of the water load, so the observations so far can also be assumed to represent the situation during normal operation in the operating phase.

6.6 WASTE AND BYPRODUCTS AND THEIR HANDLING

6.6.1 ASSESSMENT METHODS

The following sections describe the quantities and treatment of conven-tional, hazardous and radioactive waste generated at the encapsulation plant and disposal facility and assess the associated environmental impacts as an expert assessment.

6.6.2 IMPACT ON WASTE VOLUMES AND ITS TREATMENT

6.6.2.1 WASTE AND WASTE MANAGEMENT

Waste management in Finland is governed by the Waste Act (646/2011) and the Government Decree on Waste (179/2012). In addition, waste collection is guided by the general waste management regulations of the municipality of Eurajoki. Primarily, the producer of waste must reduce the amount and harmfulness of the waste generated. However, if waste is generated, it must preferably be prepared for re-use, or secondarily recycled. If recycling is not possible, the waste must be recovered by other means, including energy recovery. If recovery is not possible, the waste must be disposed of.

The operation of the encapsulation plant and disposal facility generates small amounts of municipal waste typical of normal industrial activities, as well as hazardous waste such as waste oils, solvents, batteries, accumulators and fluorescent tubes. The composition and properties of the waste do not differ from those of the waste from other industrial plants. Hazardous waste is placed in interim storage at the plant in appropriate facilities and delivered to the treatment facility. Municipal waste is sorted separately into paper, carton, wood, glass, metal, plastic, energy waste, biowaste and mixed waste. This waste is delivered for recovery.

6.6.2.2 NUCLEAR WASTE MANAGEMENT OF THE ENCAPSULATION PLANT

The waste management obligation concerning the low and intermediate level operating waste arising from Posiva's final disposal operations is transferred to TVO, which will process, store and place in final disposal this waste in accordance with its established procedures. TVO has more than 40 years' experience of operating waste. The waste generated at Posiva's encapsulation plant is of the same type as that generated at TVO's plants, for instance in connection with annual outages.

In addition to the Nuclear Energy Act (990/1987), nuclear waste to be placed in final disposal is covered by STUK's regulation on the safety of nuclear waste disposal (Y/4/2018). According to the regulation, nuclear waste must be handled safely, and the waste destined for final disposal must be classified with sufficient precision. The information to be given on the waste destined for final disposal is also described in STUK's nuclear power plant guidelines (Guide YVL D.5 "Disposal of nuclear waste”). In accordance with the instructions, records shall be made of the waste destined for final disposal showing at least the following information per waste container:

- the type of waste, its treatment and type of packing and its structural and material properties relevant to safety;
- identification and location of the container in the disposal repository;
- the radioactivity of the major nuclides as estimated upper limit values, in the case of spent
- fuel per final disposal canister and in the case of other wastes per disposal location; and
- for spent fuel final disposal canisters, also the calculated effective growth factor and heat generation.

At the encapsulation plant, radioactive waste is mainly generated in the fuel handling cell, the decontamination centre and the transfer corridor of the transport container, if the surface of the container is contaminated and contaminates come off. In the handling cell, solid waste from the fuel (activated corrosion products as well as any pieces of fuel) is collected and placed in final disposal together with the fuel elements.

Low-level liquid waste is mainly generated from the solutions used in the steel lining of the handling cell and the decontamination centre and, if necessary, in washing of the transport container, fuel drying and the decontamination centre, for example. Water collected by floor drainage in the radiation controlled area is also classified as low-level waste, unless measurements can show that the water is clean. Water that has been found to be clean can be led to the drainage system of the plant area. Final disposal of all radioactive waste takes place in solid form. According to the current plan, liquid radioactive waste is to be dried in barrels. If filter resins are used, they can be solidified, for example in a polymer.

Equipment removed from the handling cell is decontaminated prior to repair. The filter masses of the cleaning solutions are solidified. If the equipment cannot be repaired, it is decontaminated and released from control or packed and delivered to the disposal repository.

The controlled area and handling cell ventilation filters, as well as the vacuum system filters, are packed and delivered to the disposal repository.

The largest share of radioactive waste is generated during the decommissioning of the encapsulation plant. In connection with the decommissioning of the encapsulation plant, any radioactive substances left in the systems and equipment as a result of contamination are taken care of. All equipment in the handling cell is packed and taken to the disposal repository for operational and decommissioning waste. The steel liners of the handling cell and the active workshop are washed clean, but the liners are not dismantled. The wash water is solidified. The estimated total amount of operational and decommissioning waste from the encapsulation plant is approximately 640 m^3 *(Paunonen et al. 2016).*

6.7 NOISE AND VIBRATION

6.7.1 ASSESSMENT METHODS

During the operating phase of the encapsulation plant and disposal facility, the work steps causing noise are mainly excavation, crushing and traffic. Noise impacts have been assessed using the results of noise measurements carried out at Olkiluoto; design data; noise modelling carried out in connection with Posiva’s EIA procedure in 2021 *(Ramboll 2021);* and information and standards on ambient noise levels.

Ramboll has performed calculations on the noise caused by the Olkiluoto area operations and planned operations in the spring and autumn of 2021 *(Ramboll 2021).* The noise survey is largely based on previously prepared surveys *(Ramboll Analytics Oy 2007, Insinööritoimisto Paavo Ristola Oy 2006a and 2005).* Noise calculations have been performed using the SoundPLAN calculation programme (version 8.2), which is based on a common Nordic industrial and road traffic noise calculation model and takes into account the 3D terrain model. Noise zones were calculated for daytime (LAeq 7-22) and night time (LAeq 22-7). Among other things, the model took into account elevation curves, terrain shapes, buildings, acoustically hard surfaces, obstacles and other factors. The model calculates noise levels in the environment, taking into account factors such as distance attenuation, airborne sound absorption, obstacles, reflections and the absorption properties of the ground surface. Roads and water surfaces are modelled as hard surfaces.

In accordance with the previous noise modelling prepared in 2007, the new modelling has taken into account Teollisuuden Voima Oyj's power plant units OL1, OL2 and OL3, the port and Fingrid Oyj's gas turbine power plant.

Compared to the previous noise model, the wind farm located on the island of Olkiluoto (demolished) and Teollisuuden Voima Oy's power plant unit OL4 have been removed from the model. The noise modelling has taken into account the vehicle traffic on Olkiluodontie.

Vibration has been estimated on the basis of monitoring results obtained during the construction of ONKALO.

6.7.2 CURRENT NOISE SITUATION

The noise level in the Olkiluoto area is affected by Posiva's ONKALO construction site, TVO's existing power plant units Olkiluoto 1 and 2, the construction site of the new power plant unit Olkiluoto 3, the port and Fingrid Oyj's gas turbine power plant. Noise at Olkiluoto has been determined by annual measurements and more extensive noise calculations in 2007, 2005 and 2006.

Posiva's most significant source of environmental noise is quarry crushing, LWA = 122 dB. Crushing is done during the year in cycles during daytime. The noise area maps describe the noise situation when crushing is being performed. In this case, noise at the Munakari holiday homes is at the daytime limit value of 45 dB or slightly above it. When the crusher is located on the west side of the quarry dumping hill, the hill effectively limits the spread of noise to the east. The western edge of the Natura 2000 area in the vicinity of the Olkiluoto visitor centre has 40–45 dB of crushing noise during the day. When no crushing is being carried out, Posiva's noise is considerably lower than shown, and the limit values are not exceeded in Munakari either.

The noise areas of the ventilation fans on the ONKALO construction site and the flue gas fans in the ventilation building are practically limited to the Posiva factory yard area. In the nearby Natura 2000 conservation area, the sounds of the fans are likely to be audible, but below the guideline levels. The guideline value is not exceeded in the Natura 2000 area due to Posiva fan noise.

The nuclear waste encapsulation plant is quiet in terms of noise emissions, with a total sound power level determined as LWA = 92 dB. Its operation does not increase the ambient noise levels in the area or cause the guideline values to be exceeded.

6.7.3 NOISE AND VIBRATION IMPACT

Earthworks, blasting, quarry material processing, crushing and the use of vehicles and machinery generate noise and vibration. In earthworks, the most significant activities causing noise are excavation, quarry crushing and drilling.

The disposal repository for spent nuclear fuel is constructed gradually as spent nuclear fuel is placed in final disposal. During construction, the crushing of the quarry material generates noise in the daytime. The crushing of the quarry material will end once all the spent nuclear fuel has been placed in final disposal in the Olkiluoto bedrock.

The nuisance caused by noise and other disturbance during excavation and crushing in the vicinity of the encapsulation plant and disposal facility can be mitigated by scheduling the work steps for daytime. The quarry pile is used in crushing as noise protection. The crushing plant and quarry pile can be located so that there are no buildings left in the noise and dust areas *(Haapalehto et al. 2021, Kaisko et al. 2019).*

The Olkiluoto seismic system has been used to measure the effects on the bedrock from the construction sites for the disposal facility and the encapsulation plant. The Olkiluoto seismic system has been used to measure the effects on the bedrock from the construction sites for the disposal facility and the encapsulation plant. The blasting at the construction site of the disposal facility has had a maximum magnitude of around ML=1.4. The excavation work for the encapsulation plant has had a maximum magnitude of around ML=1.5. At both construction sites, more than 99% of the blasts fall below magnitude ML=1.0, and 90% fall below ML=0.5.

The most significant findings have been excavation-induced micro-earthquakes in 2017 and 2018 at the disposal facility. The magnitude of the micro-earthquakes has been ML=-0.5 at most. Compared to the excavation blasts, the micro-earthquakes release around 1,000 times less energy.

Depending on the wind conditions, the blasting sound from surface excavation can be heard for around one kilometre, or even two kilometres in sea areas **(LT-Konsultit Oy 1998).** There are no significant environmental impacts, considering the duration and timing of the excavation and the size of the affected area.

The audibility of the underground blasting sound has been assessed on the basis of mines located at a similar depth. Mines use larger amounts of explosives in a more open space, making the sound source more powerful. The noise from the excavation of the disposal repository is not heard outside the facility area *(Tolppanen & Kokko 1998).*

The noise from the crushing plant has been estimated according to the instructions of the Finnish Road Administration. The guideline value of the Noise Protection Act for residential areas is 55 dB(A) during the day. A correction of 5 dB(A) is made to the impact noise measurement result. The Finnish Road Administration (1993) defines the protection distances of crushing plants according to 50 dB(A). The noise level for normal conversation is 50–60 dB(A), and the noise level in a quiet residential area at night is 40 dB(A). The sound level falls below 50 dB(A) at a distance of less than 500 metres and below 40 dB(A) at less than 1,200 metres. The attenuating effect of structures or terrain has not been taken into account in the distances (Finnish Road Administration 1993).

If the quarry is placed at a distance of 50 m from the crushing plant, the noise level falls below 50 dB(A) already less than 200 m away, and below 40 dB(A) slightly more than 500 m away (Finnish Road Administration 1993). If the combined effect of forest and terrain were taken into account in addition to the quarry, the level would probably be below 40 dB(A) some 500 m from the crushing plant. At Olkiluoto, the shortest distances from the crushing station to the beach or cottages are around 500 metres *(LT-Konsultit Oy 1998).*

As is shown below, the noise impacts of crushing and dumping are not significant due to the short duration of the functions and the small size of the affected area.

6.7.3.1 RESULTS OF THE OLKILUOTO NOISE SURVEY

The daytime and night time noise zones caused by Olkiluoto's operations (LAeq 7-22 and LAeq 22-7) are shown in the figures (Figure 6-9 to Figure 6-11). The figures (Figure 6-9 and Figure 6-11) show the daytime and night time noise zones in a situation where TVO's nuclear power plant units Olkiluoto 1, 2 and 3 are in operation, the encapsulation plant is in operation (not at night) and ONKALO's ventilation fan is running, and the port is active in the daytime figure (Figure 6-9). The figure (Figure 6-11) shows the average daytime noise level in a situation where TVO's nuclear power plant units Olkiluoto 1, 2 and 3 are in operation and the port, encapsulation plant and gas turbine power plant are running.

Vibration

The Olkiluoto seismic system has been used to measure the effects on the bedrock from the ONKALO construction site. So far, no significant change has been observed. The status of Olkiluoto is constantly monitored through measuring devices, and through the system it is possible to monitor in real time what has happened at the excavation site for the disposal repository. The blasting at the ONKALO site has had a maximum magnitude of around 0.7.

6.8 VEGETATION, ANIMALS AND CONSERVATION AREAS

6.8.1 IMPACT ASSESSMENT AND METHODS

The impact of the encapsulation plant and disposal facility on the flora and fauna are primarily related to the land areas required for buildings and structures and the related construction work. The direct and potential indirect effects of the project have been assessed as expert work. The results of observations made in the Posiva area have been used in the evaluation. Based on these

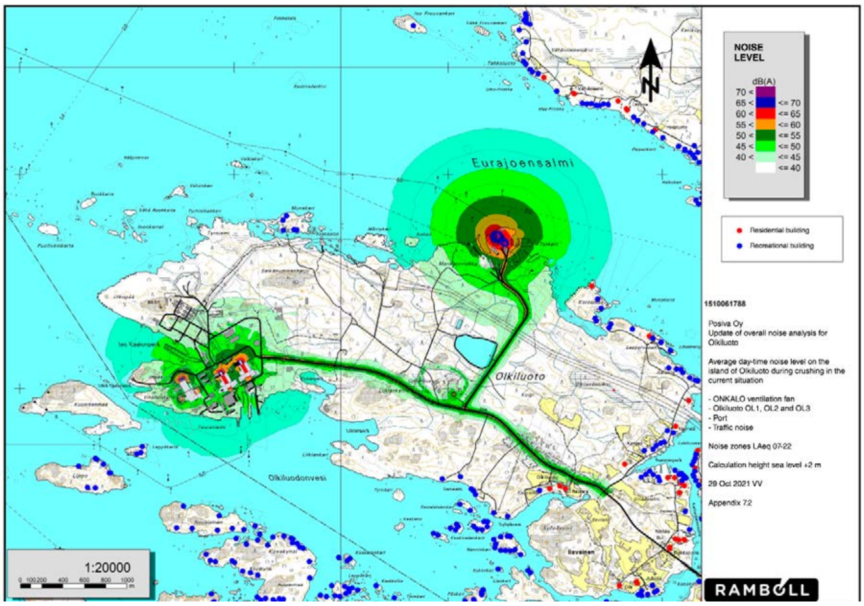


Figure 6-9. The average daytime noise level on Olkiluoto Island, LAeq7-22. The noise sources are ONKALO's ventilation fan, Olkiluoto power plant units OL1, OL2 and OL3, the port and the road traffic.

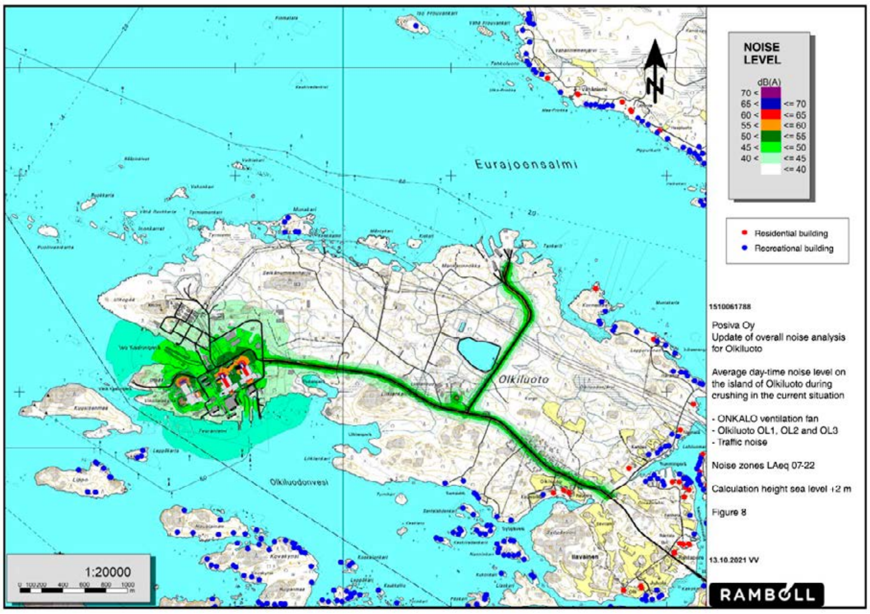


Figure 6-10. The average night time noise level on Olkiluoto Island, LAeq22-7. The noise sources are ONKALO's ventilation fan, Olkiluoto power plant units OL1, OL2 and OL3 and the road traffic.

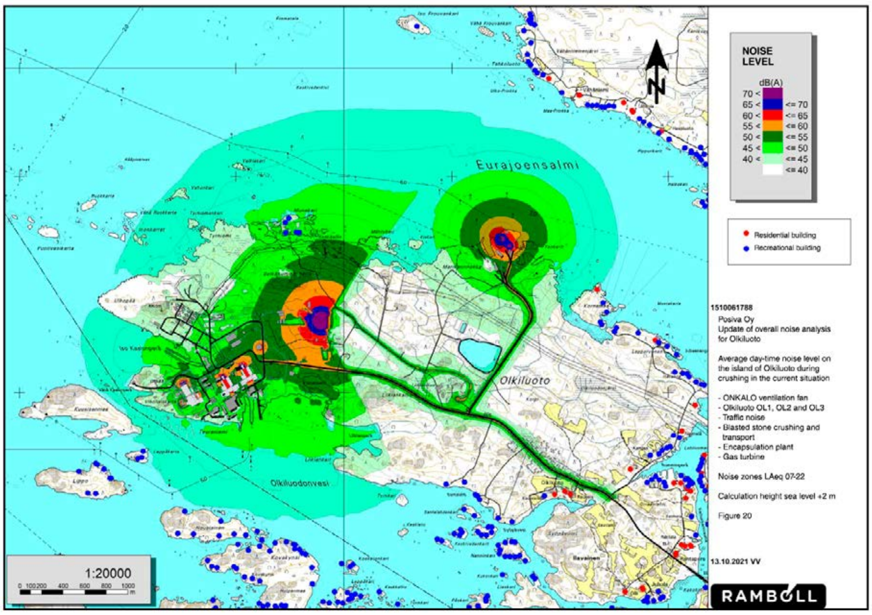


Figure 6-11. The average daytime noise level on Olkiluoto Island, LAeq7-22. The noise sources are quarry crushing and transportation, ONKALO's ven-tilation fan, Olkiluoto power plant units OL1, OL2 and OL3, the port, the encapsulation plant, the road traffic and the gas turbine power plant.

results, the impacts of the project on biodiversity and interactions have been assessed. The assessment work has examined whether the project, either alone or in combination with other projects and plans, is likely to significantly impair the natural values underlying the protection of the nearest Natura areas and nature reserves.

6.8.2 CURRENT STATUS OF THE NATURE IN THE AREA

6.8.2.1 VEGETATION AND ANIMALS

Olkiluoto belongs to the coast of the Gulf of Bothnia, where land upheaval is rapid, around six millimetres a year (Eronen et al. 1995). The lowness of the land and the rapid upheaval cause a change in vegetation as the habitat changes. The marshy meadows of the upheaval areas are bordered by a shrub zone consisting mainly of willow, sea buckthorn and myrtle. Between the shrubs and the forest there is an alder zone, which in the Olkiluoto area consists almost exclusively of common alder.

In the phytogeographical division, Olkiluoto belongs to the South Boreal zone, and within it to the anemone zone, which is characterised by demanding forest plants such as blue and white anemones. The coastal vegetation of the area is characterised by a division into zones that is constantly changing with rapid land upheaval. The zones of vegetation are reflected on the coast in that coastal forests are wetter and more lush than inland forests. Inland, forests become drier and more rugged depending on the depth of groundwater. At Olkiluoto, however, this division into zones is not clear, as the island's elevation differences are small and there are lush habitats both on the waterfront and inland. The most rugged habitats, on the other hand, are clearly located at the highest points of the island.

With the exception of the Liiklankari nature reserve, the Olkiluoto area is a coastal area with natural conditions typical for southwestern Finland, where the fauna, flora and soil are very similar to those in the surrounding areas. Undeveloped beach areas, especially on the north shore, represent natural, often lush coastal biotopes.

The biodiversity of Olkiluoto is moderately abundant, but few rarities or endangered species have been found in the area (*Ramboll Oy 2014).*

There are approximately 570 hectares of forests owned by TVO on the island of Olkiluoto. According to a biodiversity study conducted in 2013 *(Ramboll Oy 2014),* the majority (approximately 50%) of Olkiluoto's forests are fresh-heath coniferous forests. Around 20% of the forest area is grove-like heath and 20% semi-dry heath. The remaining 10% consists of dry heath, rocky soil and small grove areas. The groves are alder- and spruce-dominated, moist and fresh coastal groves. The majority of the island's forests are intensively managed commercial forests. Old forest patterns are mainly found only in Liiklankari and Kornamaa. There are also small areas of old-growth forest on the northwest side of Liiklankallio and Olkiluodontie; on Selkänummenharju and south from it; and in the Lepporvonen rock area. In the grown-up forest of Tyrniemi in the northwestern part of the island, thinning had been carried out, which left only a strip of deciduous waterside forest. At the tip of Tyrniemi are two sparsely wooded open bogs, which are the result of the overgrowth of small barren ponds.

The majority of Olkiluoto's forests are in forestry use; 36% of the forest area had been felled or planted between 2004 and 2014 (Korhonen et al. 2016). The small amount of private lands, and the forests managed by Metsähallitus outside the Liiklankari Natura area, are also in intensive forestry use, and there are no natural or similar mixed forests in the area. The southern part of the island has a much wetter soil than the northern part, which is reflected in a slight marshiness and a higher number of tubular plants that tolerate or favour moisture. There are few shrubs in the forests, and the majority of the shrub layer consists of seedlings of tree species growing in the area, as well as juniper. As a rule, there is no decaying wood in the forests used for forestry in the area. *(Insinööritoimisto Paavo Ristola Oy & Ramboll Oy 2007b.)*

Rocky forests are characterised by being in their natural state. All rocky forests have open rock areas where lichens and short shrubs grow. Peat-covered cliffs also occur, but they are very small in surface area. Common alder grows in thin strips on the shore, and together with the meadowsweet growing in the field layer, it forms a zone surrounding the whole island. On the shores, common reed forms an almost uniform belt around the island. Low meadows are rare on the island. The reasons for this are the eutrophication of the Baltic Sea, the spread of settlements and drainage. *(Insinööritoimisto Paavo Ristola Oy & Ramboll Oy 2007b.)*

The nesting birds of Olkiluoto are quite diverse and abundant, but do not differ in their species from the surrounding areas. The status of local birds has been investigated over the years through several studies. The land birds at Olkiluoto were surveyed using the line counting method during 2013 *(Ramboll Oy 2014)*, and the birds of small islands and the nearest islets were surveyed using the line counting method during 2009–2015 *(Alho & Sojakka 2018).*

Based on line counts done in 2013, the density of land birds at Olkiluoto is 237.3 pairs/km2, which is higher than the average for the Satakunta region (225 pairs/km^2). The most common nesting species at Olkiluoto were the chaffinch and the willow warbler. Other common species were the great tit, the goldcrest and the redwing. Of noteworthy or otherwise rare species, word warblers, rosefinches, red-backed shrikes, sandpipers, a black woodpecker and a merlin were found in the count. Treecreepers dependent on decaying wood were abundant at Olkiluoto *(Ramboll Oy 2014)*. It has been observed that the Olkiluoto land bird population has become rich in species that tolerate human activities well. Species that favour spruce forests, such as black grouse, have become less numerous *(Yrjölä 2009 .)*

According to circular counts carried out during 2009–2015, the most common species observed in the waters near Olkiluoto were cormorants, Arctic terns, common gulls and black-headed gulls. Other common species were the common tern and the grey gull. When comparing the results of the 2009–2015 circular counts with the corresponding waterfowl counts conducted between 1980 and 1991, it was found that there have been a few rather significant changes in bird populations. Species of the outer archipelago, such as the eider and the velvet scoter, have declined compared to previous observations. Meanwhile, species of lush waters, such as the mute swan and the grey gull, have become more abundant. The cormorant population has also increased in Olkiluoto's water areas, as in other Finnish sea areas. The numbers of some species, such as the mallard and the goosander, have remained fairly stable since the 1980s. Changes in the species represent trends typical of the surrounding area *(Alho & Sojakka 2018).*

According to the 2008 survey, the most valuable areas in terms of birds were the southern shore nature reserve, the western and northern shores and the islets in front of them. The central part of the island and the environs of the power plants have been greatly changed by human activities, as a result of which the birds in the areas have also changed greatly. *(Yrjölä 2009.)* According to the 2013 bird surveys, the following endangered species were found in the Olkiluoto area: endangered (VU) bank swallow, tufted duck, Slavonian grebe and lesser black-backed gull. The populations of these species have declined sharply in recent decades. Of the species listed in Annex I to the European Union Birds Directive (79/409/EEC), the barnacle goose, hazel grouse, black grouse, Slavonian grebe, grey heron, crane, corncrake, common tern, Arctic tern, eagle owl, black woodpecker and red-backed shrike were found in the area *(Ramboll Oy 2014).*

In 2009, a survey of small mammals, ants, mussels and earthworms was carried out in the Olkiluoto area. Bank voles and field voles were found during the monitoring of small mammals. 104 ant nests and nine species were found. 14 species of terrestrial gastropods and seven species of earthworms were found. Overall, species numbers were quite low, and due to the normality of the habitats studied, no rare species were found. *(Nieminen et al. 2009.)* Neither were rare species detected in the 2008 small mammal survey; of the six species observed, the bank vole was the most abundant *(Nieminen & Saarikivi 2008).*

The size of the elk population in the Olkiluoto area has been estimated at three to five specimens, counted at the end of the hunting season. Between 2004 and 2015, an average of three elks were hunted in the area each year (the figure includes calves and adults). The size of the white-tailed deer population is estimated at about 15 specimens at the end of the hunting season. Between 2004 and 2015, an average of 10 specimens were hunted in the area each year. The population sizes of white-tailed deer and roe deer vary somewhat from year to year, but have remained stable over the long term. Conversely, a downward trend can be detected in the size of elk populations. Among other species, the raccoon dog, mink, fox, mountain hare, squirrel and brown hare are thriving in the Olkiluoto area. In addition, lynx, badgers and martens have occasionally been observed in the area *(Niemi & Nieminen 2018).*

Surveys of the clouded Apollo, an endangered and legally protected butterfly, were made in the Olkiluoto area in spring and summer 2007 (Ramboll Oy 2007) in connection with the partial master planning of the area. These results were updated with a biodiversity survey conducted in 2013 (Ramboll Oy 2014). Based on the surveys and previous studies, the area is probably a habitat of the clouded Apollo and part of a larger metapopulation, parts of which are located on the island of Olkiluoto and its vicinity. Important surroundings for the clouded Apollo include the sunlit edges of the fields in the northeastern part and the yard areas. The Liiklankari nature reserve is not a suitable habitat for the species. *(Ramboll Oy 2007.)* The 2013 survey also investigated the occurrence of highly endangered (EN) fourleaf mare's tail and chaffweed. Neither species was observed in this study, but the presence of chaffweed in the almost unvegetated coastal areas of Liiklankari is possible, as the environment of the area has remained suitable for the species. In addition, habitats of two endangered moss species (alternateleaf archidium moss and luminous moss) were observed in the Liiklankari nature reserve *(Ramboll Oy 2014).*

6.8.2.2 CONSERVATION AREAS

Natura areas, nature reserves, nature conservation programme sites and other nationally valuable nature sites (SYKE 2021) located within a radius of around five kilometres are shown in the accompanying Figure 6-12 and Table 1. The operation of the Olkiluoto nuclear facilities has not caused significant harm to the habitat types protected by the Natura areas, which means that it has been possible to undertake the construction of the infrastructure needed by the nuclear facilities in harmony with the state of the environment and without unnecessarily jeopardising the natural and environmental values.

6.8.3 IMPACTS ON VEGETATION, ANIMALS AND CONSERVATION AREAS

The project's impacts on the flora and fauna are primarily related to the land areas required for buildings and structures and the related construction work. There are no significant impacts during the operation and after the closure of the disposal repository. The environmental impacts of the piling and crushing operations were monitored between 2003 and 2015 by collecting wet deposition and needle samples in the vicinity of the work area. Rock dust is accumulated on the surface of the needles, which is reflected as larger aluminium and iron concentrations in unwashed needles. Based on chloroform washing of the needle samples, which breaks their surface slightly, it could however be stated that the higher concentrations cannot reach the cells. During the monitoring, it was found that heavy metal concentrations on the needle surfaces were on the decrease. Rock dust is not expected to have long-term effects on the forests of Olkiluoto. (*Aro et al. 2018)*

Most of the plants take their water from the soil water above the rock surface. Therefore, any reduction of the rock groundwater level caused by the underground facilities will not impact the flora. As stated in Section 6.3.3, a significant drop in water level in ground layers is not expected to occur.

The noise of quarry piling and crushing operations randomly reaches levels that could have a disturbing effect on the nearby bird nesting area. However, the piling and crushing noise is not continuous; it lasts for a few days at a time. The most important areas for birds (such as the Liiklankari old-growth forest conservation area) do not extend to the area with the heaviest crushing noise. Mammals are not usually disturbed by even loud noise. The noise during the operating activities of Posiva's nuclear facilities will be slight and mainly related to traffic in the area and the ventilation of buildings (see Section 6.7.31). The effects of noise on nature are estimated to be minor.

On the basis of study, the impact of the excavation vibration on the fish population is irrelevant due to its short duration and local nature *(Kala- ja vesitutkimus Oy et al. 1996).*

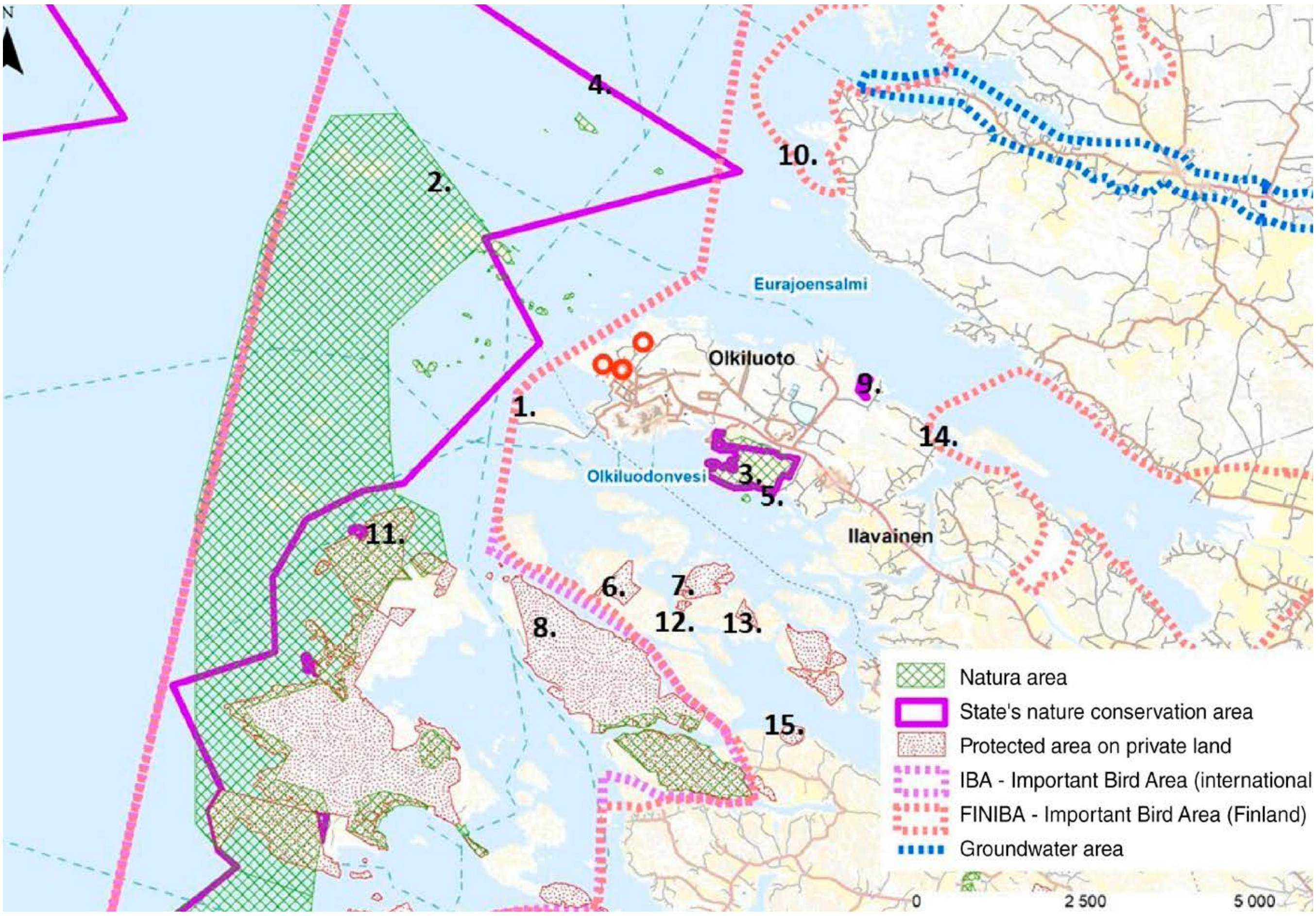


Figure 6-12. Natura 2000 sites, nature reserves and nationally valuable nature sites located in Eurajoki. The numbering extends 5 km from the Olkiluoto power plant area.

1. **Rauma-Luvia** archipelago IBA area (27,360 ha) and Rauma–Luvia–Pori archipelago FINIBA area (27,371 ha). The Rauma-Luvia archipelago, one of Finland's internationally important IBA bird areas, is a large, unified archipelago and an important seabird nesting area. The area is part of the Rauma–Luvia–Pori archipelago, one of Finland's important FINIBA bird areas (Leivo et al. 2002).

2. **Rauma** archipelago Natura area (FI0200073, SAC, 5,350 ha). The Natura area includes the outer archipelago of the Bothnian Sea and the archipelago of the sea zone, which are important for seabirds. It also includes parts of the inner archipelago, which contain, among other things, groves that are valuable in terms of their vegetation (Southwest Finland ELY Centre 2013a). The nearest small islands in front of Olkiluoto included in the Natura area are located around one kilometre northwest of the project area. The Natura area includes the Liiklankari forest area in the southern part of Olkiluoto Island (site 5). A large part of the Natura area located south and southwest of Olkiluoto is included in the Raumanmeri nature and hiking area (site 8) and the Laukkari nature reserve (site 11). The northern part of the Natura area belongs to the Bothnian Sea National Park (site 4). The Natura area covers most of the beach areas included in the Rauma archipelago coastal protection programme (site 3). Almost the entire Natura area is included in the IBA and FINIBA bird areas (site 1).

3. **Rauma** archipelago coastal protection programme area (RSO020020). Most of the area is included in the Rauma archipelago Natura area (site 2).

4. **Bothnian** Sea National Park (KPU020037). The National Park was established by law (326/2011) for the protection and management of the underwater nature, archipelagos and islets, coastal wetlands and related species of the Bothnian Sea, the conservation of natural and cultural heritage, and general nature recreation, education and research, as well as monitoring of environmental change. The national park includes approximately 91,200 hectares of land and water. As a separate small area, the national park includes a small body of water to the west of Kornamaa Island north of Olkiluoto.

5. **Liiklankari** Nature Reserve (VMA020001). The Liiklankari nature reserve (57.5 ha) in the southern part of Olkiluoto is included in the national old-growth forest protection programme (AMO020001) and the Rauma archipelago Natura area (site 2).

6. **Kääntentila** Nature Reserve (YSA239598). A nature reserve (19.4 ha) located south of Olkiluoto in Kivi-Reksaari.

7. **Ympyriäinen** Nature Reserve (YSA239819). A nature reserve (22.2 ha) located south of Olkiluoto on Ympyriäinenmaa Island. It covers most of the island, with the exception of built-up beach areas.

8. **Raumanmeri** Nature and Hiking Area (YSA236619). Established in 2016, the nature reserve covers approximately 1,100 hectares and includes a significant part of the Rauma archipelago, bordering the Bothnian Sea National Park. Among other things, the area includes significant parts of the islands of Reksaari, Omenapuu and Nurmes, which have value in terms of nature conservation and cultural history. From Nurmes Island, included is the Mustanperä site of the old-growth forest protection programme (AMO020321). Parts of the area are included in the Rauma archipelago Natura area (site 2) and the coastal protection programme area (site 3).

9. **Kornamaa** old-growth forest protection programme site (AMO000093). Small forest area located near the northern shore of Olkiluoto in the western part of Kornamaa Island.

10. **Kuivalahti** FINIBA area (1,026 ha). One of Finland's important FINIBA bird areas, Kuivalahti is a diverse coastal

area that rapidly changes from a shallow open-sea shoreline to a sheltered cove and extensive flads (Leivo et al. 2002).

11. Laukkari Nature Reserve (YSA024635). A two-part nature reserve (118.6 ha) southwest of Olkiluoto in the northern part of Aikonmaa Island. Almost all of the area is included in the Rauma archipelago Natura area (site 2).

12. Vasikkakari Nature Reserve (YSA239926). A small nature reserve (1.5 ha) located south of Olkiluoto in the southern part of Ympyriäinenmaa Island.

13. Mäntyrinne Nature Reserve (YSA206416). A nature reserve (6.0 ha) located south of Olkiluoto on Taipalinenmaa Island.

14. Eurajoki estuary FINIBA area (1,605 ha). The Eurajoki estuary, one of Finland's important FINIBA bird areas, is a diverse estuary containing wetlands, agglomerations, fields and coastal groves (Leivo et al. 2002). The area is located east of Olkiluoto.

15. Vähämaa Nature Reserve (YSA239599). A two-part nature reserve (12.4 ha) on the Taipalmaa peninsula, approximately five kilometres south of Olkiluoto.

Table 1. Natura 2000 areas (green), nature reserves (yellow) and other nationally valuable nature sites (white) at a distance of around 5 km from the site of the Olkiluoto power plant.

Number	Location	Description
1	Rauma-Luvia (-Pori) archipelagos	IBA area and FINIBA area
2	Rauma archipelago	Natura 2000 area
3	Rauma archipelago	Coastal protection programme area
4	Bothnian Sea National Park	National Park
5	Liiklankari Nature Reserve	Nature reserve, old-growth forest protection programme area, included in the Rauma archipelago Natura area
6	Kääntentila Nature Reserve	Nature reserve
7	Ympyriäinen Nature Reserve	Nature reserve
8	Raumanmeri Nature and Hiking Area	Nature reserve
9	Kornamaa	Old-growth forest protection programme area
10	Kuivalahti	FINIBA area
11	Laukkari Nature Reserve	Nature reserve
12	Vasikkakari Nature Reserve	Nature reserve
13	Mäntyrinne	Nature reserve
14	Eurajoki estuary	FINIBA area
15	Vähämaa Nature Reserve	Nature reserve

There are no nationally endangered plant or animal species in the area reserved for final disposal activities. No regional ecological connections are cut off. Outside the area reserved for the operation of the disposal facility, the exploitation of natural resources, such as mushroom and berry picking, hunting, fishing and forestry can be continued in the current way.

There are no nationally or provincially significant natural areas or Natura 2000 sites in the area reserved for final disposal activities. The location belonging to the Natura 2000 network closest to the encapsulation plant and disposal facility is the Liiklankari old-growth forest in the southern shore of Olkiluoto, which is part of the Rauma Archipelago Natura 2000 area. According to calculations made with the Olkiluoto surface hydrology model *(Karvonen 2020)*, the amount of water discharged into rock tunnels has at most a very small impact on the growth of plants in the Liiklankari nature reserve. In other areas, groundwater-impacted nature sites are so far from the possible construction area that there are unlikely to be any effects. After the closure of the facilities, the groundwater level will recover within a few years.

The Natura habitats of the Liiklankari conservation area have been listed in inventories completed in 2006. Species in the area (beetles, aphyllophores, mosses and macrofungi) were charted in the autumn of 2006. According to the Natura assessment carried out in 2006, the projects (including the disposal facility) made possible by the master plan at Olkiluoto do not significantly affect the values for which the Liiklankari area has been included in the Natura 2000 conservation programme. The measures will not have a significant effect on maintaining a favourable level of protection for the network of old-growth forests in southern Finland. *(Insinööritoimisto Paavo Ristola Oy 2006b.)*

6.9 NATURAL RESOURCES

6.9.1 ASSESSMENT METHODS

Impacts on the utilisation of natural resources refer to both the use of natural resources and the prevention of their use. This report describes the use of natural resources and its effects. Regarding the utilisation of natural resources, the utilisation of the quarry generated and the consumption of the materials needed for the project (including bentonite and copper) have been examined, among other things.

6.9.2 EFFECTS ON UTILISATION OF NATURAL RESOURCES

6.9.2.1 USE OF COPPER

The amount of copper needed annually in the operating phase is less than 0.01% of the world's annual production and, for example, less than 1% of the annual production of the Pori unit of Luvata Oy. The availability of the oxygen-free copper that Posiva needs is good enough. Copper is a commonly used material worldwide, and its availability can be expected to be good also in the future. If necessary, copper products can also be purchased in stock in the future to ensure continuity.

6.9.2.2 USE OF BENTONITE

Bentonite is a clay that consists of strongly expanding clay minerals that are not found on a large scale in Finland. The annual amount of bentonite required in the operating and decommissioning phases is less than 0.1% of the world's annual production. The availability of bentonite is good. Bentonite is commonly used for various purposes, and its availability can be expected to be good also in the future.

6.9.2.3 USE OF ROCK MATERIAL

The rock material brought up from the underground disposal repository is stored in a quarry material dumping area at Olkiluoto. The crushed rock material generated in the full drilling process is transported to the surface like quarry and dumped. The material does not have to be crushed further, but can be used for other applications as is.

6.10 PEOPLE, COMMUNITY STRUCTURE, REGIONAL ECONOMY AND IMAGE OF EURAJOKI MUNICIPALITY

6.10.1 ASSESSMENT METHODS

During the environmental impact assessment work, the effects of the disposal facility project on human health, comfort, recreation and living conditions have been investigated, including changes to land use; effects on the landscape; radiation dose increases due to radioactive releases; effects on traffic; and noise. In addition, the effects of possible accident situations have been examined. In selecting the priorities for the assessment, feedback from residents and people working in the area has been taken into account. It must be borne in mind that the assessment of the social impact of activities more than 60 years in the future is very uncertain. The assessment of the impact of the project on people has been served by the interaction in the monitoring group and at discussion events during the EIA procedure in 2008–09, as well as information received from various stakeholders and the media.

6.10.1.1 HEALTH EFFECTS

In accordance with the guidelines prepared by the National Research and Development Centre for Welfare and Health (Stakes 2012), "health effects" in this report refers to changes in the health of humans or the health conditions of their living environment or the threat of such changes (health risks) caused by the project. According to the guidelines, the changes may be direct or indirect, cumulative, short- or long-term, positive or negative, permanent or reversible, severe or mild. However, the main focus of this review is on identifying potential health hazards.

A health hazard is

- a disease diagnosed in humans,
- other health disorder,
- factor or condition that can reduce the health of the living environment of a population or an individual.

The main focus of the health impact assessments has been on the potential health hazards of radioactive substances. First, we look in general at how radiation from radioactive substances can affect human health. The potential for human exposure to radiation from radioactive materials during the transport of spent fuel, in the encapsulation and disposal phase and after the closure of facilities will then be assessed. The review covers both the normal situation (operations are going according to plan) and various operational occurrences and accidents. The health effects and risks arising from the project have been assessed using calculations based on radiation exposure.

In addition to the radiation effects, it has been assessed what other health effects the project may have. Harm caused by traffic, noise and dust, among others, is under consideration. The review is based on estimates of emissions from the project and of other concrete changes in the environment.

The nuclear safety management of the encapsulation plant and the long-term safety management of the disposal facility (Chapter 8) will ensure that the disposal facility will not have any health effects even in the distant future.

6.10.1.2 LIVING CONDITIONS, COMFORT AND RECREATION

Where applicable, resident surveys and other attitude surveys commissioned by Posiva have been utilised in preparing the report. The attitudes of Finnish people towards nuclear waste have been examined as part of the “Finnish Energy Attitudes” studies. The series of studies has examined and monitored attitudes towards issues of energy policy for 38 years (1983–2020) already.

The trust of Eurajoki residents in the safe disposal of spent nuclear fuel has been measured through a qualitative interview survey conducted in 2007–08 and a quantitative population survey (*Aho 2008)*, and as part of social research funded by the National Nuclear Waste Research Programme (KYT-2010) *(Litmanen et al. 2010).*

The survey of residents *(Ramboll Finland Oy 2007)* carried out in connection with the preparation of the partial master plan (2006–07) was used to find out residents’ perceptions of the current state of their living environment and to obtain information on the effects of Olkiluoto’s current operations in the area’s immediate surroundings. A total of 1,500 questionnaires were mailed to residents near Olkiluoto, people living in Eurajoki or Rauma and TVO employees. A total of 774 responses were received, and the response rate was 52%.

Opinions, attitudes and possible concerns of Eurajoki residents about the final disposal were examined in a thematic interview survey *(Pöyry Environment Oy 2008)* in June 2008. A total of 21 persons were interviewed. The interviews examined the interviewees’ views on the impact of the encapsulation plant and disposal facility on safety and the future of the municipality of Eurajoki.

6.10.1.3 COMMUNITY STRUCTURE, REGIONAL ECONOMY AND IMAGE OF EURAJOKI MUNICIPALITY

This study estimates the number of direct and indirect jobs created in the local area by the construction and operation of the encapsulation plant and disposal facility. In addition, the effects of the project on the development of the economic structure, the planning of society’s activities and the future plans of local businesses have been studied.

At their most extensive. the region structural and economical effects have been studied throughout the Satakunta region. The region economical impacts have been assessed with the help of Posiva’s work report *”Käytetyn ydinpolttoaineen loppusijoituslaitoksen aluetaloudelliset, sosioekonomiset ja kunnallistaloudelliset vaikutukset”* (Region economical, socio-economic and municipal economical impacts of the spent nuclear fuel disposal facility) *(Laakso et al. 2007).* The study was commissioned by

Posiva and carried out by Kaupunkitutkimus TA Oy in spring and summer 2007.

The effects of the project on the image of the municipality of Eurajoki have been assessed using Posiva's work report "Kuntaimagotutkimus 2006" *(Corporate Image Oy 2007).* In October–December 2006, the survey interviewed 500 consumers, 200 representatives of businesses and 200 Eurajoki residents by telephone.

6.10.2 CURRENT STATUS OF THE AREA

The current state of the area is described in Appendix 3 to the operating licence application, *"Description of settlement and other activities on the nuclear facility site and in its vicinity, including land use planning arrangements".*

6.10.3 IMPACTS ON PEOPLE, COMMUNITY STRUCTURE, REGIONAL ECONOMY AND THE IMAGE OF EURAJOKI MUNICIPALITY

6.10.3.1 HEALTH EFFECTS DUE TO IMPURITIES, NOISE AND VIBRATION

Emissions of non-radioactive substances to air and water during the research, construction and operating phases of the encapsulation plant and disposal facility, as well as operational noise and vibration, have been considered in the previous chapters. Emissions from operations and other physical changes in the environment are estimated to be minor.

The following is a summary of these assessments in terms of human health and health conditions:

- The conventional health effects of the project are minor. The increase in traffic generated by the project will not have an impact on local air quality. Traffic noise will not increase significantly as a result of the project.
- In practice, the biggest health disadvantage and factor detrimental to comfort is the noise generated by excavation and crushing work as well as blasting. The excavation will not have significant health effects on the population. The crushing station is located in the terrain so that there are no buildings in the protection zone.
- The health risks of dusting from excavation and crushing can be minimised by technical means.

6.10.3.2 HEALTH EFFECTS OF RADIATION

Health effects of ionising radiation

When considering the health hazards of radioactivity, attention is paid to ionising radiation generated in connection with radioactive decay. Among other things, the health effects and risks of ionising radiation depend on the nature, amount and target organ or tissue of the radiation. *(Paile 2002, STUK 2005.)*

In addition to the physical variable "absorbed dose", the amount of radiation in terms of health hazards is described by the variable "equivalent dose", the unit of which is sievert (Sv). The equivalent dose is calculated from the absorbed dose by multiplying it by a factor depending on the type of radiation. The factor is 1 for beta, gamma and X-rays. For neutrons it is from 5 to 20 depending on the energy, and for alpha rays 20. (Ikäheimonen 2002)

When the different significance to health and sensitivity of organs or tissues to radiation by means of weighting factors is taken into account in addition to the type of radiation, an effective dose (weighted equivalent dose) with the same unit (Sv) as the equivalent dose is specifically used to assess radiation health risks. Sievert is a large unit; it is often used as one thousandth (mSv) or one millionth (µSv).

When considering the radiation exposure of the whole population or a part of the population, the collective dose (usually the collective effective dose) is used as the variable, the unit of which is mansievert (manSv). The collective dose is the total amount of radiation doses received by individuals.

The health effects of radiation can be divided into two main groups: direct and incidental effects. Direct effects are caused by extensive cell damage due to very high radiation doses. For example, if a person receives a large dose of radiation throughout their body in a short period of time, they may die within a few weeks from a socalled radiation sickness. Early effects have occurred mainly as a result of the nuclear bombings in Hiroshima and Nagasaki, some accidents and radiation therapy.

Incidental effects, in turn, are effects that occur randomly in different individuals, due among other things, to individual differences in exposed individuals. The likelihood of an incidental effect, such as cancer, increases with increasing radiation doses, but the severity of the harm does not depend on the dose. A direct effect, such as cataracts or skin damage, occurs only when the radiation dose exceeds a certain threshold, and the severity of the harm increases as the dose increases.

It has not been possible to detect the effect of low doses of radiation even in statistical studies of large populations, because the potential effect, which has been claimed to also possibly be positive at low doses, is small; and there are many cancers due to other causes, for example.

According to some views, there are no harmful effects from radiation below a certain threshold. However, in accordance with the precautionary principle, radiation protection assumes that the probability of cancer, for example, is directly proportional to the radiation dose without a threshold. As the risk factor for cancer, the International Commission on Radiological Protection (ICRP) uses 0.0055%/mSv at low doses and low dose rates. In this case, it is assumed that in the approximately 18,000 people who have all received a dose of 1 mSv, one case of cancer would be caused by radiation *(ICRP 2007, Paile 2002, UNSCEAR 2008).*

Radiation is suspected to have hereditary effects. Although radiation has been shown to cause hereditary effects in animal experiments, it has not been possible to detect them in humans. The risk factor for serious hereditary effects of the International Commission on Radiological Protection (ICRP) is 0.0002%/mSv. For serious harm to health, the ICRP thus uses a risk factor totalling 0.0057%/mSv *(ICRP 2007).*

Comparative information on radiation sources and radiation doses in Finland

In the following, the doses received from radiation in Finland are examined comparatively.

The average annual radiation dose of Finns is approximately 5.9 mSv. Finns receive radiation mainly from nature. Around two thirds of the radiation dose received by a Finn, i.e. 4 mSv, comes from radon in indoor air. Medical use of radiation results in an average effective dose of 0.76 mSv. The average dose caused by external radiation from soil and building materials is 0.45 mSv per year per Finn. People are exposed to radiation from space everywhere; on an airplane more than on the ground. Finns receive a dose of 0.33 mSv per year from radiation from space. Humans also eat, drink and inhale natural radioactive substances. Natural radioactive substances in food and drinking water cause an internal radiation dose of around 0.3 mSv per year. The share of artificial radioactive substances in the environment in the effective dose is very small – nuclear weapons tests and nuclear accidents are estimated to cause a radiation dose of around 0.01 mSv per year. However, the amounts have been very small, and in practice they do not show as an increase in the dose that Finns receive each year from various sources. *(STUK 2021a)*

The size of the radiation dose caused by natural background radiation varies from region to region. The radon concentration in indoor air varies greatly in different regions. Finns receive their highest radiation dose from radon in indoor air. The average radon concentration in Finnish dwellings is approximately 94 becquerels per cubic metre (Bq/m^3), which corresponds to a radiation dose of approximately four millisieverts per year. The reference value for the indoor radon concentration in dwellings and other living spaces is 300 Bq/m^3 of air. New housing must be designed and built so that the radon concentration does not exceed 200 Bq/m^3. There are an estimated 70,000 dwellings in Finland with a radon concentration exceeding 400 Bq/m3. Living in a dwelling with a radon concentration of 400 Bq/m^3 causes an annual dose of around 7 mSv. The dose caused by external radiation from soil and buildings varies between 0.17 and 1.0 mSv/year at different locations in Finland. Flight personnel receive an additional radiation dose of approximately 2 mSv per year from space radiation. The radiation dose caused by Finland's currently existing nuclear power plants to the most exposed group in the vicinity of the plants is less than one thousandth of the average radiation dose of Finns. *(STUK 2021a, 2021b, 2021c, 2021d, 2021e, 2021f.)*

The radiation dose caused by the utilisation of radiation in Finland comes almost entirely from the medical use of radiation. Around 3.7 million X-rays, 2.3 million standard dental examinations and nearly 400,000 panoramic dental examinations are performed annually in Finland. When the radiation doses caused to patients from various X-ray examinations are divided among all Finns, the average dose is around 0.45 mSv per year. The average radiation dose per examination for all X-ray examinations is around 0.6 mSv. *(STUK 2021g)*

Health effects due to the encapsulation plant and disposal facility

Small amounts of radioactive material may be released from the spent nuclear fuel encapsulation plant and disposal facility during normal handling. Gaseous radon can be released into the air of the disposal repository from rock and from groundwater leaking into rock spaces. The generation of normal emissions is described in detail in the material submitted to STUK in connection with the operating licence application. Under normal conditions, radioactive substances are tightly isolated from nature and humans at all times. The main focus is thus on the consequences of various operational occurrences and accidents (Chapter 7) and on the long-term safety assessments of the final disposal (Chapter 8).

The table (Table 7-1) shows the collective doses for emissions from normal operation and emissions from operational occurrences and accidents. The normal annual releases of radioactive material are insignificant.

The annual dose to a person belonging to the population over 50 years from normal emissions is very likely to be less than 0.01 mSv in the immediate vicinity of the plant site. In this case, it has been assumed that the surrounding area is used for permanent residence and agriculture and home-grown products are the primary source of nutrition. The most significant radionuclide in terms of its effects is cesium-137.

The majority of the dose is accumulated as radionuclides deposited on the ground are transferred to agricultural products such as milk, and thus from internal radiation through food intake. The next highest dose is caused by direct external radiation from fallout and inhalation of radioactive substances in the air. Direct radiation from an emission cloud causes a much lower dose than this. Five kilometres away, the dose is at least an order of magnitude smaller than in the immediate vicinity of the plant. Further away, the dose is even lower. The doses caused by normal emissions are thus insignificantly low compared to natural radiation, for example (around 3 mSv/year). Doses from natural radon and its degradation products released into the environment are also insignificant.

The increase in natural radon gas in the environment caused by the excavation of rock spaces has been assessed based on measurements by the Radiation and Nuclear Safety Authority and Posiva's drilling results (Vesterbacka & Arvela 1998). Propagation was estimated using a Gaussian propagation model of a point source, resulting in higher than actual concentrations. Even these concentrations remain so small in the vicinity of the locations that it is practically impossible to separate them from the radon concentration in the outdoor air. No significant environmental impacts will therefore occur.

The radiation doses to the employees of the encapsulation plant are estimated to be lower than the doses received by the personnel of nuclear power plants. The amounts of radioactive substances processed at the encapsulation plant at a time are also small compared to the corresponding amounts at nuclear power plants. No harmful amount of radioactive substances is released from the encapsulation plant into the environment even in the event of a disturbance in the handling of nuclear fuel.

The suitability of the final disposal system and the final disposal site, as well as the fulfilment of safety requirements, are demonstrated by safety analyses. These examine both probable developments and unlikely events that undermine long-term safety, and assess in each case the consequences for humans and the rest of nature (Chapter 8).

6.10.4 ATTITUDES TO FINAL

DISPOSAL OF SPENT NUCLEAR FUEL

6.10.4.1 THE ATTITUDES OF FINNISH PEOPLE TO FINAL DISPOSAL OF NUCLEAR WASTE

The attitudes of Finnish people towards nuclear waste have been examined as part of the "Finnish Energy Attitudes" follow-up study. In a study conducted in 2020, more than one third (36%) consider that the final disposal of nuclear waste in Finland is safe. The proportion of people with doubts is slightly higher (38%). Attitudes to final disposal have gradually become more positive over the decades.

As before, in municipalities with power plants, nuclear waste is approached less reluctantly than on average in the country. Confidence in the safety of final disposal is significantly more widespread there, and especially in Eurajoki, which has been selected as the final disposal site. In the context of the review, it is also appropriate to recall the results of the previous phases of the research series. They have repeatedly brought out the fundamental readiness of both Eurajoki and Loviisa residents to receive nuclear waste, i.e. for disposal to occur in the territory of their own municipality. *(Finnish Energy Attitudes 2011 and 2013.)*

6.10.4.2 CONFIDENCE OF EURAJOKI RESIDENTS IN THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL

According to an interview study conducted in 2007–08 *(Aho 2008),* the attitude towards nuclear power was mainly positive, as the results of the form survey research included in the study also showed (59%).

Based on the results of the survey, approximately 40% of the municipal residents of Eurajoki who responded were positive about the final disposal of spent nuclear fuel, and 12% were neutral. However, according to the survey, about 45% of municipal residents were worried by the location of the spent nuclear fuel encapsulation plant and disposal facility in their home municipality. Based on the interviews, the biggest concern related to final disposal is the import of spent nuclear fuel from abroad to Finland and Eurajoki for final disposal.

None of the interviewees said they felt a particular need to know about disposal-related issues. More than half (approximately 56%) of the respondents felt that they had received sufficient information on matters related to final disposal. According to them, information on the subject is distributed to their homes free of charge so often that no actual information needs arise. The information available on the subject was largely seen as clear and comprehensive. The majority of the interviewees felt that they trusted Posiva's communications.

As many as 69% of the respondents thought that Posiva has good expertise in the final disposal of nuclear fuel. Posiva was considered a reliable expert organisation, with 69% agreeing with the statement that it is one. 68% of the respondents trusted the expertise of Posiva's staff. According to the results of the survey, 75% of municipal residents are interested in matters related to final disposal. *(Aho 2008.)*

According to a study carried out in 2008 by the Jyväskylä and Tampere Universities *(Litmanen et al. 2010)*, one third of the residents of Eurajoki agreed that they receive enough information about final disposal, one third disagreed and one third could not assess the matter. Based on correlation analysis, the relationship between knowledge and trust proved to be quite weak. The highest inverse correlation was found between support for the expansion of the disposal facility and the need for information on the health effects of final disposal.

Institutional trust in Posiva proved to be twofold in Eurajoki. The proportions of residents that trust and do not trust Posiva were equally high (39%). Confidence in Posiva was somewhat greater than in the public authorities. There is a strong positive relationship between trust and approval for the extension of the disposal facility.

The study found a strong positive correlation between the economic benefits and other impacts associated with final disposal (municipal image, state of the environment, etc.) and perceived trust. Residents who trusted in final disposal generally felt that the benefits of final disposal outweighed the disadvantages.

The moral responsibility experienced for nuclear waste contributes to explaining the confidence of residents. The risks and threats posed by the project, in turn, are perceived to be greatest among those residents who oppose the expansion of the disposal facility. The general acceptance of nuclear power, in turn, strongly correlates with confidence related to final disposal.

According to the study, 42% of Eurajoki residents are ready to accept the expansion of the disposal facility. As a general observation of the study, it can be stated that the trust of the residents is based not so much on information as it is on other factors explaining the trust. In addition to institutional trust, significant explanatory factors include the economic and other benefits associated with the project; perceptions of risk; moral responsibility; and the general attitude to nuclear power. It is also significant and noteworthy that over the decades, nuclear power has become a familiar technology to local residents and part of the local identity.

6.10.4.3 SURVEY OF RESIDENTS AND EMPLOYEES IN THE OLKILUOTO POWER PLANT AREA

According to a resident survey conducted in connection with the Olkiluoto partial master plan *(Ramboll Finland Oy 2007),* an important issue in the Olkiluoto partial master plan common to all respondent groups was the safety of the nuclear power plants. The nearby residents gave the most emphasis to the preservation of the existing holiday homes. In addition, they considered fishing and recreational opportunities in the Olkiluoto sea area and the development of the marina to be important. Employees, on the other hand, emphasised the importance of expanding nuclear power generation and improving transport connections. Especially those living further afield also highlighted the delimitation of the underground final disposal area and the addition of wind farms on land and sea.

In terms of final disposal, females were statistically very significantly more negative than males, and those aged over 65 were more negative than younger residents. Residents who responded to the survey had a negative attitude towards the safety of final disposal of nuclear waste and its economic benefits for the municipalities, but a positive one to the economic benefits of the third nuclear power plant at Olkiluoto (Figure 6-13). Those working at Olkiluoto were positive about both the final disposal and the OL3 plant unit.

Half of the residents who responded to the survey considered the final disposal of spent nuclear fuel to be the most harmful power plant function (Figure 6-14). Those living further afield considered power lines more harmful than nuclear power plants, while nearby residents took the opposite view.

According to open answers, information is needed the most on safety and on problems with construction. Nearby residents are particularly interested in the adverse effects of the nuclear power plant and the final disposal. Residents would also like information on issues related to the operation of the nuclear power plant and the effects on holiday homes. *(Ramboll Finland Oy 2007.)*

Results of the thematic interviews

According to a thematic interview survey *(Pöyry Environment Oy 2008)* which examined the opinions, attitudes and possible concerns of Eurajoki residents about final disposal, most of the respondents were neutral or relatively positive about the final disposal project. Out of the possible final disposal alternatives, deposition in bedrock was considered to be the best. However, there were concerns of safety risks, mainly in the long term. None of the interviewees experienced any actual fears regarding final disposal, although there were some concerns. The effects of the encapsulation plant and disposal facility on the employment rate and tax revenue were seen as positive things for the municipality.

The results were quite consistent with the study by Aho *(2008).* The most significant concerns in these interviews were transportation, the possible importation of nuclear waste from abroad and long-term safety – which, unlike in Aho's research, was associated with suspicion of earthquake risks in the minds of quite a few respondents.

"I trust that it will stay there"

A clear majority of those interviewed considered final disposal in the bedrock to be moderately safe

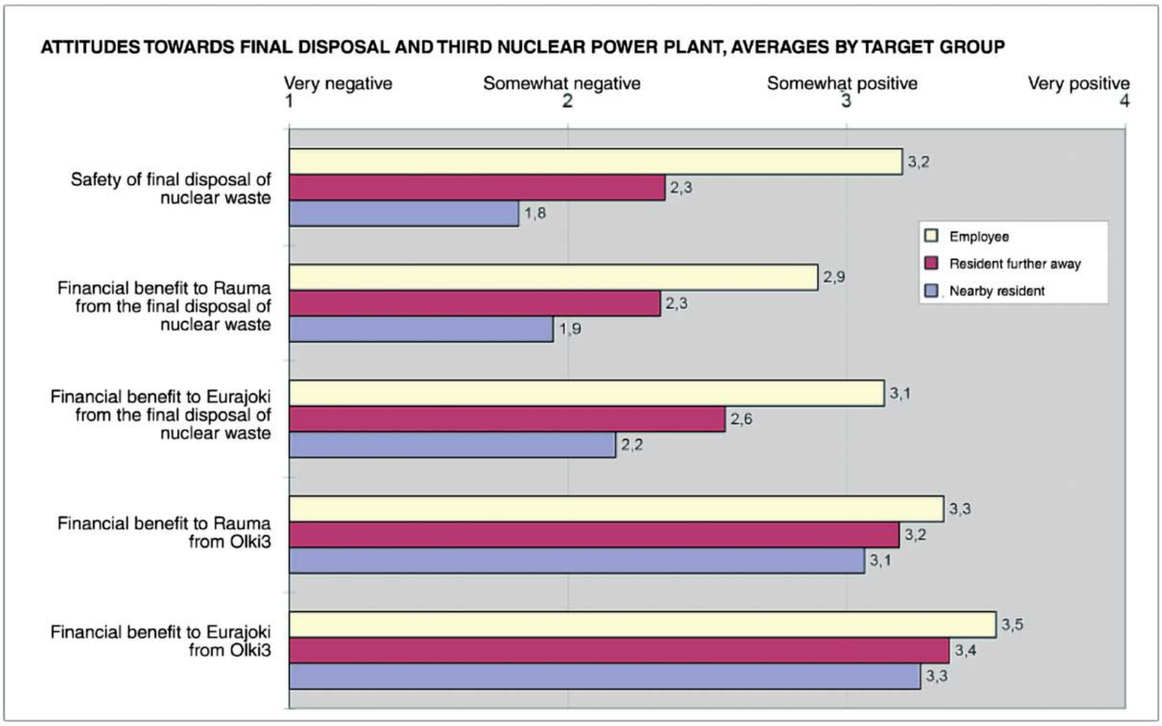


Figure 6-13**.** Attitudes to final disposal and the third nuclear power plant at Olkiluoto by focus group. “Unable to say” responses have been omitted (Ramboll Finland Oy 2007).

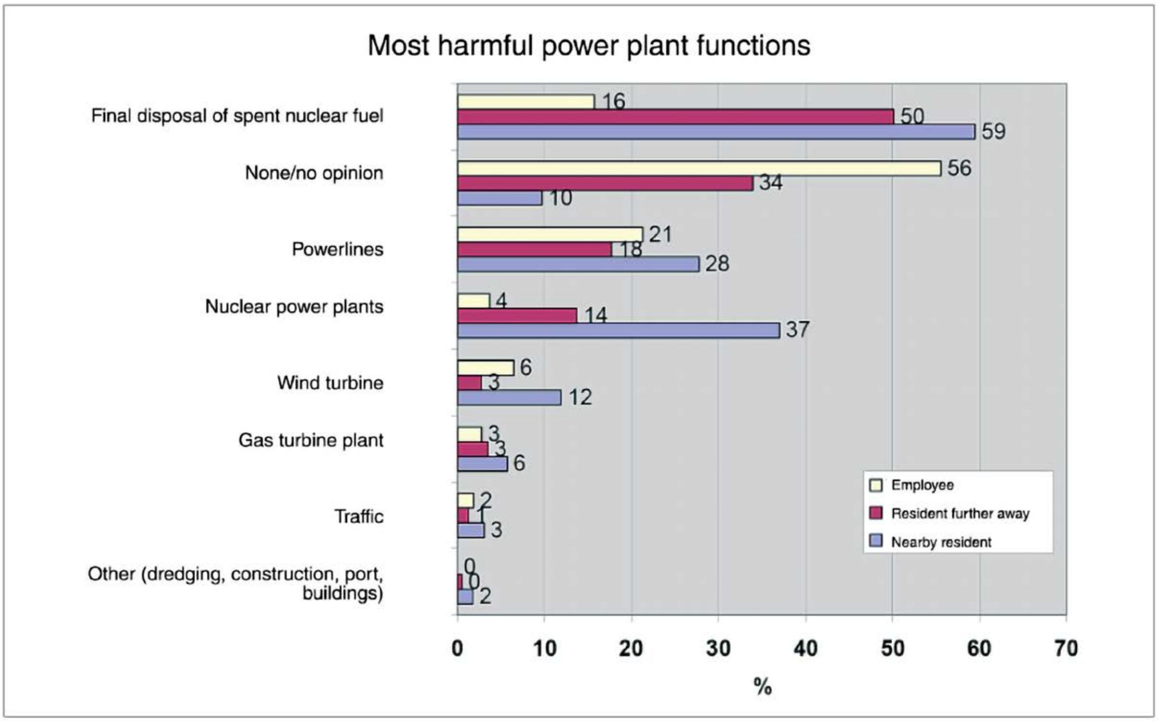


Figure 6-18. Most harmful power plant functions by focus group (Ramboll Finland Oy 2007

and stated that there was no better alternative. Processing in Finland was considered safer than taking the waste abroad, and was also viewed as a moral obligation for Finns. A few interviewees strongly criticised the final disposal. The main reasons for the criticism were doubts about long-term safety and the view that it is wrong to leave nuclear waste to future generations. On the other hand, even the critical interviewees considered that disposal in bedrock is still probably the best of the current options.

Many interviewees stated that they themselves do not understand the matter properly, but trust that things are in order. A few estimated that permission would not be granted if there were dangers. Almost everyone felt that they had received enough information about the final disposal. A few said they did not want to think about the matter in too much detail, but trusted those responsible for handling the matter. All the interviewees viewed Posiva as at least relatively reliable.

Most of the interviewees were neutral or positive about the construction of an encapsulation plant and disposal facility specifically in Eurajoki. The location next to the nuclear power plant was considered natural and also sensible in terms of minimising transportation. However, a couple of interviewees stated that waste from each power plant should be disposed of in its own vicinity. A few felt that if a good and safe place has been found, it should of course be used. Some speculated that if something were to happen, it does not really matter whether the facility is next door or further away. A few wished that the facility would rather be somewhere else.

Concerns about final disposal also emerged. Many wondered about the very long timespan of the final disposal, even if there were no concrete doubts or concerns. Unpredictable things can happen in the long run. Among other things, doubts were raised about the canisters being able to last forever. It was also considered that no human being can estimate the changes that will occur in the world over thousands of years. Almost half of the interviewees wondered whether it could be certain that there will be no sizable earthquakes in Finland even in the future. The prevalence of earthquake concern is likely due in part to the fact that a major earthquake in China had been in the news just before the interviews. A few highlighted climate change, sea level rise and its potentially unpredictable consequences. Some wondered if any possible research results unfavourable to the project would be made public.

Final disposal concerns are things that are thought about occasionally. None of the interviewees expressed any real fear of the final disposal project or stated that concerns about it would overshadow their own life or cause stress. Only one interviewee thought that final disposal could pose a risk to personal safety.

Otherwise too, the interviewees felt that their lives as a whole were secure. Among other things, the feeling of safety was affected by one's own health and work situation, while in the case of a few it was weakened by nuclear power plants among other considerations. Younger respondents in particular felt accustomed to the power plants. Some of the local residents also stated that they were used to nuclear power, while others remembered Olkiluoto before the power plants and stated that the area is no longer the same.

The most concrete concerns regarding final disposal concerned the transport of nuclear waste, which was considered by many to be the most critical step. Both land and sea transport caused suspicion. Half of the interviewees raised concerns that nuclear waste would also be imported to Eurajoki from abroad. With the exception of one respondent, all those who mentioned this possibility were strongly opposed to it. Interviewees were aware that the law prohibits the import of nuclear waste, but stated that the law could be changed. The reasons mentioned were the foreign ownership of Finnish energy companies and the possible greed of the owners of the disposal facility. The interviewees considered the idea that Finland would become a "nuclear dump" for Europe to be very negative, and considered that each country should manage its own nuclear waste on its own territory.

"The future of the municipality looks pretty bright"

All interviewees stated that they were comfortable living in Eurajoki. It was difficult to specify the source of the comfort, but the small size and tranquility of the municipality, the closeness to nature and the sea, and the good services in relation to size all came to the fore. Admittedly, smallness was also partly seen as a factor that weakened comfort. A couple of respondents considered the nuclear power plants to be a factor undermining the comfort of the municipality.

A large majority of the interviewees expected to live in Eurajoki in the future as well. For most, the plans for the future focused specifically on their current location and not on Eurajoki as a municipality. Many strongly expressed their intention to live in their current home for as long as possible.

Six of the interviewees planned to move out of Eurajoki. Mostly these were the youngest interviewees who were planning to engage in studies elsewhere. The future after studies had hardly been planned. Two hoped to return to

Eurajoki and two considered it unlikely. Eurajoki was considered to be a good living environment for one's future family and children. All parents of young children considered Eurajoki a good place to live and planned to stay in the locality. Three persons stated that moving away would not be ruled out, for example because of work. Possible relocation plans were related to one's own life, with the final disposal contributing to the issue in only one case.

According to most of the interviewees, the future of Eurajoki looks bright. The municipality was judged to be on financially sound footing, and jobs and life were expected to be in good supply in the future. TVO and the revenues coming from it were considered important; a couple of interviewees also mentioned Posiva in this context. Several pondered a possible municipal merger, which was viewed as an unwelcome possibility. Other issues that arose were the ability of decision-makers to act in the interest of the municipality and the responsibility for the preservation of nature and beaches.

When discussing the impact of the encapsulation plant and disposal facility on the future of the municipality and residents of Eurajoki, most saw it to have positive effects. Positive effects on employment and the economy were seen as the main factors, although only a few assessed the effects as significant. Some of the interviewees estimated that the jobs would be for local residents, while some assumed that the majority of the workforce would come from elsewhere. A few estimated that the encapsulation plant and disposal facility could slightly improve their own chances of getting a job locally.

The encapsulation plant and disposal facility was thought to have two types of effects on population growth and willingness to move. On the one hand, jobs can bring in more people; on the other hand, it was speculated that some families would not want to move to a municipality known for nuclear waste. Some even believed that people already living in the municipality might move out for this reason. A few interviewees also highlighted the potential safety risks associated with final disposal when discussing the future of the municipality.

The differences between the groups of respondents were quite small, both between females and males and between different groups of respondents. Half of the females were at least slightly negative about the project, while the majority of males were neutral. Females were somewhat more concerned; on the other hand, more females also said they were confident that the matter would be handled properly. Males saw slightly more positive effects on the municipality.

Almost all those who had a negative attitude were nearby residents, who also had more concerns than young people. Among other things, concerns about waste, transport and earthquakes were more common among nearby residents than among young people. Nearby residents were clearly more attached specifically to their current home than the young. Many nearby residents were concerned about the area expansions and possible expropriations at Olkiluoto. Many also had concrete local concerns, such as concerns about borehole water, traffic safety on Olkiluodontie and the actual durability of the bedrock. *(Pöyry Environment Oy 2008.)*

6.10.4.4 IMPACTS ON THE COMMUNITY STRUCTURE, REGIONAL ECONOMY AND IMAGE OF EURAJOKI MUNICIPALITY

According to a 2007 report (Laakso et al. 2007), the decision on the location of the encapsulation plant and disposal facility, Posiva's relocation to Eurajoki, renovation of Vuojoki Manor and renewal of its operation as well as the commencement of the plant and facility's research stage and the construction of ONKALO have had a positive effect on the socio-economic, region economical and municipal economical developments in Eurajoki and the entire region in the early 2000s. However, the facility project alone does not explain the changes that have taken place; the impact of the Olkiluoto 3 nuclear power plant project in particular is greater. In addition, there are several other factors that have had a positive impact on the development of the Eurajoki region and Satakunta as a whole, such as the general economic development in the early 2000s, the EU Structural Funds programmes and the Regional Centre Programme. *(Laakso et al. 2007.)*

Employment impact

The total employment impact of the design, research and construction phase of the encapsulation plant and disposal facility in 2001–2025 will be approximately 6,800 person-years (py), of which 4,200 py will be the direct impact and 2,600 py the indirect impact. At their highest, the direct employment effects of the entire project per year are around 325 person-years. During the operating phase, the immediate employment impact has been estimated to be approximately 130 person-years annually. The indirect employment effects of the project are estimated to be around 2/3 of the direct effects. It is estimated that the project's impact on the overall employment rate will be at most approximately 550 person-years annually.

Of the total employment effect (direct and indirect effects), a maximum of around 45 person-years/year is allocated to the municipality of Eurajoki. In the operational phase of the plant, the share of Eurajoki has been estimated at around 30 person-years/year. For the entire region, the encapsulation plant and disposal facility will have a significant employment impact. In addition, employment in construction and through indirect effects is also expected to be significant in the region. During the operational phase of the plant, its employment impact in the region is estimated to be around 90 person-years annually. In the whole of Satakunta, the project is estimated to employ a maximum of 300 person-years/year, and 125 person-years/year during the operational phase.

A significant part of the indirect effects of the project are estimated to be channeled outside the province to other parts of the country, especially during the construction phase. Although the national employment effects are quite large at their highest compared to the regional ones, their significance for employment at the national level remains marginal. For this reason, the effects on the municipality and region of Eurajoki are of particular interest, these being significantly positive for employment in the municipality and the region. In Eurajoki, the project is estimated to increase the municipality's employment rate by a maximum of less than 2% annually, and in the region by less than 1%. *(Laakso et al. 2007.)*

Demographic effects

The encapsulation plant and disposal facility will create more jobs for the municipality where it is located and the surrounding impact area, which will increase the population of the area and change the demographic structure. The population impact of the facility project has a rejuvenating effect on the age structure of the municipality of Eurajoki.

The effects of the facilities on the population are in turn reflected in the demand for housing and thus in construction and community structure.

Effects on the municipal economy

The construction and operation of the encapsulation plant and disposal facility will impact the municipal economy. In this respect, by far the largest effects of the plant are on the property tax and its effect on inter-municipal tax revenue equalisation. It is estimated that a maximum of 3.5 million euros will be paid on the disposal repository in property tax. Rising property tax revenue also affects the tax revenue equalisation of the municipality of Eurajoki, but only partially.

Posiva's role in Eurajoki and the surrounding region

According to the study on the region economical impacts (*Laakso et al. 2007),* in the municipalities of the region there is satisfaction with the positive region economical impacts of the project. It is viewed as particularly positive that the construction and operation of the encapsulation plant and disposal facility are long-term activities with relatively foreseeable effects that are distributed over a long period. The co-operation between Posiva and the municipalities is mainly estimated to work well. Posiva's operations and investment in the renovation of Vuojoki Manor and the renewal of its activities are appreciated. *(Laakso et al. 2007.)*

The potential negative external effects that were earlier associated with the encapsulation plant and disposal facility have not materialised. Based on the available information, the facility project has not disturbed the residents or companies, and the awareness of and image of Eurajoki municipality have strengthened. *(Laakso et al. 2007.)*

Effect of the encapsulation plant and disposal facility on the image of the municipality of Eurajoki

According to a study of the effects of the project on the image of the municipality of Eurajoki *(Corporate Image Oy 2007),* the representatives of businesses were clearly more positive about the final disposal of spent nuclear fuel than the other groups of respondents. It should be noted that the feelings of Eurajoki residents about final disposal were clearly more positive than those of consumers in Finland in general. On the other hand, consumers in southern and western Finland were more positive about final disposal than they had been eight years earlier.

All groups of respondents (residents, consumers, businesses) assessed the effects of final disposal on the municipal image of Eurajoki more positively than they did before the disposal decision in 1998. Eurajoki residents' assessments of the effects of final disposal on their home municipality were clearly more positive than those by other consumers. The effects of the final disposal on the attractiveness of Eurajoki as a place of residence, a tourist destination and a location for businesses were all areas that were clearly associated with more positive estimates than negative ones.

All Eurajoki residents interviewed knew about the Olkiluoto nuclear power plant, and with the exception of a few respondents, it was also known that the municipality had been chosen as the final disposal site for spent nuclear fuel.

The residents of the municipality associated Eurajoki especially with being a good place to live, good development and dominance by agriculture and forestry. Comparing the results with the 1998 survey, Eurajoki residents now considered their municipality to be clearly a more attractive, developing and interesting tourist destination. 66% of Eurajoki residents associated their municipality with the description "a safe municipality to live in", which is clearly more than their assessment of other municipalities included in the study.

Half of the consumers who responded to the survey knew that Eurajoki had been chosen as the final disposal site. The majority of consumers still believed that final disposal would weaken the attractiveness of Eurajoki as a tourist destination and place of residence, although the assessments were more positive than before. One third of consumers believed that final disposal would have a positive effect on its attractiveness as a location for businesses.

Two thirds of the representatives of businessves knew Eurajoki to be a final disposal site. Representatives of businesses still assessed the impact of the final disposal on the attractiveness of Eurajoki as a residential and tourist municipality quite critically, although the assessments by this target group were also more positive than before. *(Corporate Image Oy 2007.)*

7 IMPACTS OF OPERATIONAL OCCURRENCES AND ACCIDENTS

7.1 ASSESSMENT METHODS

The safety of nuclear waste facilities is governed by STUK regulation STUK Y/4/2018. In the safety regulations, the requirements are classified separately for a foreseeable period of the next few thousands of years and a longer period involving major climate change. During the foreseeable period, the upper limit of the annual radiation dose from final disposal to the most exposed person has been set at 0.1 mSv.

The long-term safety of the solution is paramount in the final disposal of spent nuclear fuel. Long-term safety refers to the safety of the final disposal after the encapsulation plant and disposal facility has ceased operations and the rock facilities have been closed. Safety is ensured through long-term research and development activity. Research activities determine the suitability of bedrock conditions for final disposal and assess its effects on safety.

The long-term safety of the final disposal is demonstrated by a safety case. The safety case consists of a series of separate reports setting out the starting points for the safety assessment, the models and initial data used, the assessment methods, the assessment results, associated uncertainties and conclusions on the safety reviews and their reliability. The safety analyses included in the safety case are described in Chapter 8.

The following sections discuss the effects of accident situations on human health and the environment, based on safety analyses and the requirements set for the encapsulation plant and disposal facility. The consequences of exceptional situations have been assessed on the basis of a wealth of existing research data on the health and environmental effects of radiation. The radiation doses during postulated operational occurrences and accidents have been estimated.

7.2 SAFETY PRINCIPLES

The main safety principles of the encapsulation plant and disposal facility include reliance on the proven technology in use; utilisation of technology specifically developed for final disposal operations; a high level of safety culture; continuous development of the organisation and the activity management system; and user experience activity. The safety principles also include the operation and decommissioning of the plant in accordance with the safety-technical operating conditions, the aging management of the plant, condition monitoring and maintenance, radiation measurements and the control of releases of radioactive substances.

The design solutions for the encapsulation plant and disposal facility are largely based on proven technology already in use. Finland and the rest of the world have long experience in the design, construction and operation of both nuclear power plants and rock facilities. Nuclear power plants also have more than 40 years' experience in the handling of spent nuclear fuel in Finland. In part, the design is based on specially developed technology. It is to be expected that technological developments will continue to offer new options for technical details. The same types of methods are used in technical design and safety assessment as are used in the design and safety analyses of currently existing nuclear power plants. An independent comparison is used to verify the correctness of the experimental and computational methods used.

Nuclear power plants, which form the central background to Posiva's operations, have a well-developed safety culture in Finland. This refers to the way of thinking, attitude, way of acting and work atmosphere prevailing in the organisation, which emphasises the safety of the operation of the plant and the prioritisation of safety-relevant aspects at all stages of operations. This in turn means safety awareness; high levels of professionalism; careful working practices; and vigilance and initiative to detect and eliminate safety hazards. A similar safety culture is also followed in Posiva's operations. The open principle of publicity adopted in research in the nuclear waste sector in Finland contributes to the maintenance and further development of the safety culture.

The development and maintenance of Posiva's organisation and activity management system ensures that the design, construction and operation of the encapsulation plant and disposal facility are continuously compliant. Continuous monitoring and evaluation of user experiences and the resulting improvements are an integral part of operational development. As the operating phase of the encapsulation plant and disposal facility will be considerably long (in the order of 100 years) due to the commissioning of new nuclear power plant units, the basic refurbishment and modernisation of Posiva's nuclear facilities will also be relevant during the operating phase.

7.3 RADIATION PROTECTION

According to Section 7h of the Nuclear Energy Act (990/1987), *"nuclear waste shall be managed so that after disposal of the waste no radiation exposure is caused which would exceed the level considered acceptable at the time the disposal is implemented".* The design basis for the encapsulation plant and disposal facility is that the radiation exposure of the personnel and the environment is kept as low as is practicable.

In accordance with the Radiation and Nuclear Safety Authority Guide YVL D.5, the final disposal of spent nuclear fuel must be based on the safety functions related to technical barriers preventing the release of radioactive substances into the bedrock for at least approximately 10,000 years. Safety must be ensured by multiple barriers, so that significant environmental and health impacts are avoided even if individual barriers do not work as expected for some reason.

The safety requirements for final disposal are set out in STUK regulation STUK Y/4/2018. Safety requirements are defined by the annual allowed radiation dose to an individual and the limits on average radioactive releases. The encapsulation plant and disposal facility and its operation must be designed in such a way that

- the radiation exposure of the employees of the plant is limited by all practicable measures and in such a way that the maximum values laid down in the Government Decree on Ionising Radiation *(1034/2018)* are not exceeded;
- the discharges of radioactive substances into the environment remain negligible when the plant is operating without disturbance;
- as a result of anticipated operational occurrences, the effective annual dose to a representative person is less than 0.1 millisieverts (mSv);
- as a result of a postulated Class 1 accident, the effective annual dose to a representative person is less than 1 mSv;
- as a result of a postulated Class 2 accident, the effective annual dose to a representative person is less than 5 mSv;
- in cases of expansion of the postulated accident, the effective annual dose to a representative person is less than 20 mSv.

Releases of radioactive substances into the environment from the uninterrupted operation of the encapsulation plant and disposal facility can be considered insignificant if the average annual effective dose to the most exposed persons in the population does not exceed 0.01 mSv. Effective annual dose means the effective dose caused by external radiation received over a period of one year and by radioactive substances entering the body during that time. The effective dose is the weighted sum of the equivalent doses of exposed tissues and organs, where the equivalent dose is the average energy transferred from the radiation to the tissue or organ per unit mass, multiplied by the radiation weighting factor.

Anticipated operational occurrence means an incident affecting safety whose occurrence during the lifespan of the facility is relatively likely (expected to occur at least once during any period of a hundred operating years). As a result of an operational occurrence, radioactivity may be released into the plant premises and radiation dose rates may increase there. Small amounts of radioactive substances may enter the vicinity of the facilities.

A postulated accident is an event that is used as a design basis for the safety functions of the encapsulation plant and disposal facility and has a low probability of occurring during the lifespan of the facility. As a result of a postulated accident, spent nuclear fuel may break, and radioactive substances may be released into plant facilities or the environment.

Using the nominal factor of the ICRP, the probability of harm to health caused by a radiation dose of 1 mSv to an individual is not more than 0.0057% in the first year, and lower in the following years. Given the low probability of accidents, the probability of health damage caused by accidents remains lower than what the radiation dose from the accident represents. The health risk to the population as a whole is also not significant compared to risks such as that from natural radiation, as the farther a person lives, the lower the dose would be.

The same dose limits apply to the operating personnel of the encapsulation plant and disposal facility as to the operating personnel of the nuclear power plant. The dose limits are given in the Government Decree on Ionising Radiation *(1034/2018).*

7.4 OPERATIONAL OCCURRENCES AND THEIR CONSEQUENCES

Anticipated operational occurrences defined for the encapsulation plant and disposal facility are typically due to either incorrect actions or various equipment failures. Operational occurrences leading to the possible release of radioactivity are situations in which radioactivity can be released to the plant premises from the systems containing it. Based on the analyses, the annual radiation doses to a representative person in an individual operational occurrence situation remain insignificantly small, i.e. around 0.002% of the set annual dose limit of 0.1 mSv *(Räihä 2021).*

As a result of operational occurrences, radioactive substances from discharges could be detected by measurement in very low concentrations in the immediate vicinity of the plant, and also possibly further away. The detection of concentrations would be hampered by natural background radiation and artificial radioactive substances from elsewhere. Measuring the total dose rate would not detect changes in the ambient radiation situation.

Among other things, radiation doses and health risks depend on the environmental characteristics of the encapsulation plant and disposal facility, such as the size, location and lifestyle of the population and the climate conditions.

7.5 ACCIDENT SITUATIONS AND THEIR CONSEQUENCES

The structure of the encapsulation plant and disposal facility will be such that any accidents which may occur to the nuclear fuel at various stages of processing, resulting in damage to the fuel, will not pose an immediate health hazard to personnel or to local residents. Fuel elements shall only be handled in areas of the encapsulation plant whose walls are dimensioned to attenuate direct radiation from the fuel to a non-hazardous level. In the event of an accident, the ventilation of the controlled area of the encapsulation plant can be stopped or the exhaust air can be led through filtration, in which case any radioactive substances released into the air can be filtered in a controlled manner. Solid and liquid radioactive materials that may have entered the fuel handling facilities in the accident situation are collected for further processing. However, the small amount of radioactive gas, mainly krypton (noble gas), released from the fuel that could potentially be broken in an accident is difficult to recover.

Accidents can be caused by serious equipment failures or exceptional external events. Efforts have been made to prevent accidents caused by handling errors by the appropriate design of equipment and functions. The above-ground encapsulation plant is also structurally dimensioned against assumed external events. Among other things, these include an aircraft collision with a building, earthquakes and floods.

A criticality accident, i.e. an uncontrolled fission chain reaction maintained by free neutrons in nuclear fuel, could occur if the fuel elements formed a suitable fuel concentration filled with water. The possibility of an accident is structurally prevented in the nuclear fuel handling and storage facilities in such a way that the situation is practically impossible.

In postulated accidents and their expansions, the initial event is typically the fall of a heavy load such as a transport container, container lid, fuel element or final disposal canister. In these accident situations, particles of different sizes can be released from the fuel rods, in addition to gaseous and other substances that are easily released into the air. In postulated accident situations, radioactive substances are initially released inside the facility to the premises of the radiation controlled area. Exhaust air filtration from these spaces is assumed to operate normally.

The doses to the representative person were clearly below the annual dose limits in all the accident cases analysed. As a postulated Class 2 accident, a case was analysed where a transport container falls from a receiving facility to a transport container transfer corridor. In the basic case, the radiation dose of a representative person caused by the filtered release through the exhaust ventilation system of the controlled area is 0.01 mSv. As a case of sensitivity, a case was also analysed where electricity is lost and emissions are released into the outside air partly through leaky openings in the building. This case came closest to the dose limit, as the dose of 2.30 mSv to a representative person is almost half of the 5 mSv annual dose limit (*Räihä 2021).*

The conclusion is that the normal operation of the encapsulation plant and disposal facility or their operational occurrences and accidents will not cause danger to the personnel or the surrounding population. In terms of emergency plans, this means that there is no need for emergency preparedness in the situations discussed, except for the measures required in an alert situation. Assuming the simultaneous occurrence of several malfunctions can lead to an accident more serious than the design basis, in which the unfiltered release of radioactivity into the environment could require the initiation of protection measures at the plant and in its immediate vicinity.

The significance of the external radiation dose from fallout increases as the observation period lengthens. External exposure accounts for the majority of the dose accumulated over 50 years. In the short term, however, annual dose levels remain so low that there is no risk of immediate health effects. The risk of stochastic effects also remains low. In neighbouring countries, doses would be lower by several orders of magnitude; the distance from Olkiluoto to the Swedish mainland is more than 200 kilometres.

Radioactive substances released in the event of an accident and the radiation doses caused by them could be detected by measurements in the environment. The extent and shape of the impacted area would depend on the magnitude of the emissions and the prevailing weather situation. The detection would be hampered by natural background radiation and artificial radioactive substances from elsewhere.

8 LONG-TERM SAFETY

8.1 ASSESSMENT METHODS

The criteria for the safety planning of the planned encapsulation plant and disposal facility in terms of limiting the release of radioactive substances and the environmental impact are presented in this report. An assessment of the possibilities for meeting the applicable safety requirements has also been presented. The assessment is based on the safety case (SC-OLA) prepared in 2021 for the operating licence application for the encapsulation plant and disposal facility, which demonstrates the long-term safety of the final disposal of spent nuclear fuel. Preliminary safety case material for the alternative horizontal disposal solution was completed in 2007 (Smith et al. 2007), and partly updated in 2016–17 *(Posiva SKB, 2017).*

The initial plan for the safety case of the spent nuclear fuel disposal repository to be built at Olkiluoto was prepared in 2005 *(Vieno & Ikonen 2005),* and it was checked and updated in 2008, 2012 and 2021 *(Posiva Oy 2008, 2012c and 2021)*. The safety case consists of a series of separate reports setting out the starting points for the safety assessment, the models and initial data used, the assessment methods, the assessment results, associated uncertainties and conclusions on the safety reviews and their reliability.

The safety analyses included in the safety case examine the radiation doses associated with both the probable developments and unlikely events that undermine long-term safety over several thousand years. Over a longer period, the release rates of radioactive substances into the living environment associated with these events and developments will be assessed.

Conservative estimates of radiation doses and radionuclide release rates are presented in the safety analyses. The purpose of the analysis is to determine the consequences for humans or other nature of the failure of one or more release barriers and the release of radioactive substances from the disposal repository into the living environment. The safety analyses also address uncertainties related to the behaviour of the final disposal system and to the assessment of various possible events and developments. When assessing risks, the probability of events is taken into account. Radiation doses and release rates have been compared with the safety requirements set out in legislation, Finnish Government decisions and YVL Guides published by STUK.

8.2 SAFETY CASE FOR THE DISPOSAL FACILITY

Long-term safety is assessed using a safety case. Figure 8-1 shows the approach used to establish a safety case for the final disposal of spent fuel, defining design bases; assessing the operational capacity of the disposal repository; and generating and analysing scenarios leading to the release of radionuclides. The preparation of the safety case is an iterative process, and the results of previous analyses are taken into account in the definition of performance requirements, bedrock target characteristics, design requirements and the bedrock classification system.

The safety case is a set of reports consisting of eight main reports and supplementary background reports. The main reports are: *Design Basis, Initial State, Low and Intermediate Level Waste Repository Assessment (LILW-RA), Performance Assessment and Formulation of Scenarios (PAFOS), Analysis of Releases, Models and Data, Complementary Considerations and Synthesis* (Figure 8-2). The set of safety case documents demonstrates the compliance with the requirements related to long-term safety.

The surface environment is also part of the final disposal system. As a result, it is assessed in accordance with the safety case methodology, and the assessment is included in the scope of the PAFOS, Analysis of Releases and Models and Data reports. The Analysis of Releases report includes an analysis of the radionuclide release scenarios and their radiation effects available from the PAFOS and LILW-RA reports. The Synthesis report includes a summary of the reasons for Posiva’s understanding of the

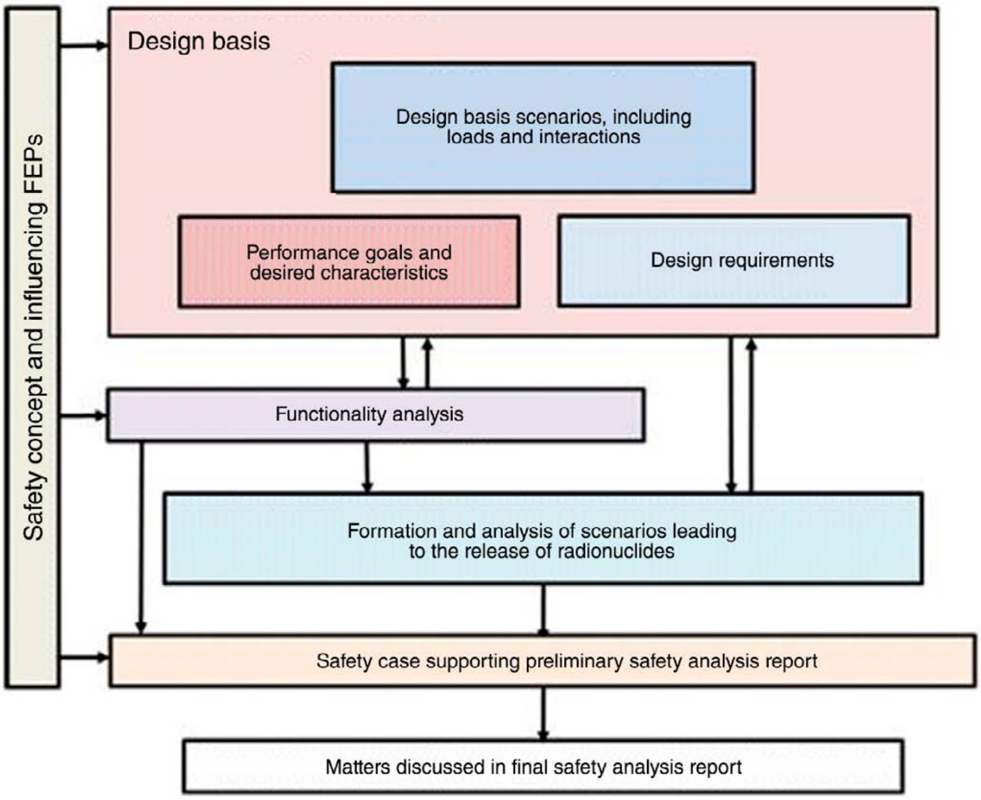


Figure 8-1. Approach used in preparing the safety case (FEP phenomena, events and processes). .

Figure 8-2. The set of safety case documents development costs of the final disposal system; an assessment of compliance with official regulations; and an assessment of the reliability of the long-term safety and security assessment of the geological disposal of spent fuel to be built at Olkiluoto.

8.3 SAFETY REQUIREMENTS

According to the Radiation and Nuclear Safety Authority regulation STUK Y/4/2018, the final disposal of nuclear waste must be planned in such a way that the radiation effects resulting from the developments considered probable do not exceed certain limit values. Radiation effects are considered separately for the period in which human exposure to radiation can be estimated with sufficient reliability and for subsequent periods. The first period shall be at least several thousand years, in which case the annual dose received by the most exposed persons must be less than 0.1 mSv.

The more distant the future, the more difficult it is to assess the radiation doses to an individual. For this reason, in later reference periods the maximum value will no longer be set for the radiation dose received by humans but for the amounts of radioactive substances released into the living environment. The Radiation and Nuclear Safety Authority sets these limit values in such a way that the radiation effects caused by final disposal can be at most equivalent to the radiation effects caused by natural radioactive substances in the earth's crust. Radionuclide-specific limit values expressed as radioactive releases (in units of Bq/year) are given in Guide YVL D.5 "Disposal of nuclear waste", which also contains other detailed safety regulations.

According to the guideline:

"Compliance with the requirements concerning nuclear safety and radiation safety and the suitability of the disposal method, engineered barriers and disposal site shall be demonstrated by means of a safety case that shall study both developments considered to be likely and ones caused by rare events impairing long-term safety."

The alternative development paths included in the safety case are called scenarios. According to Guide YVL D.5, they must be systematically formed from phenomena, events and processes that may be relevant for long-term safety. The consequences of these scenarios are described below in the section on radionuclide transport.

8.4 CASES EXAMINED

In the safety case, the examination of the final disposal system and developments in its environment is divided into performance assessment and analysis of *radionuclide release scenarios.*

The performance assessment addresses the fulfilment or non-fulfilment of the performance targets in different development scenarios, which cover the main uncertainties related to the future development of the entire final disposal system. As its initial data, the performance assessment describes the rock and the built underground system with its associated uncertainties, the most important of which are presented as undetected quality deviations in the underground disposal facility, as initial-state faults. Uncertainty about future climate developments is covered by two alternative climates, the uncertainties in which are based on the RCP scenarios of the International Panel on Climate Change but extend the descriptions of climate developments over the entire review period of one million years. This includes 7–8 ice ages with their preceding permafrost and subsequent temperate climate episodes. One of the scenarios corresponds to the expected course of development, assuming that the release barriers operate as planned. The performance analysis looks at four different time periods separately:

1. Early stage of development up to 10,000 years;
2. The rest of the temperate period until the next permafrost phase;
3. The next permafrost phase and subsequent glaciation;
4. The time of repeated glacial cycles up to one million years.

The scenarios formed in the performance assessment have been divided in accordance with the Decree and the YVL Guides as follows:

- *Baseline scenario:* The goals set for the safety functions are met.

- *Variant scenarios:* More broadly, situations where the final disposal system is malfunctioning.

Disruption scenarios based on unlikely developments, in which highly unlikely events that compromise long-term safety cannot be completely ruled out.

In addition to the above, the performance assessment creates a scenario in line with the expected course of development, in which the release barriers operate as planned, but which takes into account the identified potential initial-state faults.

The performance assessment confirms that when the release barriers operate as planned, i.e. as expected, any radioactive releases from the disposal facility will not only take place in the distant future, but also be well below the limits set by the radiation safety authority. However, in the context of uncertainties, it is possible that the consequences of significantly worse-than-expected conditions or unlikely events will be significantly greater. But even in this kind of case, the radioactive release limit values set by the authority are not exceeded. This supports the view of the reliability of performance assessment. In addition, some highly unlikely human-induced events have been identified that could disrupt the disposal repository.

Modelling of the release and transport of radionuclides examines the radiological effects of radionuclides that may be released from the disposal repository, as well as the uncertainties associated with these estimates. The uncertainties can be divided into three categories: (i) scenario-related uncertainties; (ii) model-related uncertainties; and (iii) parameter-related uncertainties. Uncertainties related to the scenarios have been identified and addressed as part of the performance analysis as described above. Uncertainties related to the models and parameters are handled by deterministic and probability-based analyses in accordance with the applicable YVL Guide (YVL D.5, sections A08a and A09). Deterministic analysis consists of individual calculation cases that separately consider some of the uncertainties associated with the assumptions or parameters of the model. In probability-based analysis, a large number of cases are calculated by varying the parameter values according to the selected probability distributions.

The calculation cases analyse releases in the baseline scenario and under unlikely or hypothetical developments. The baseline scenario assumes that the performance targets of the release barriers are met, in which case the release of radionuclides is only possible from the low and intermediate level waste disposal repository. The unlikely and hypothetical developments are based on scenarios identified in the performance analysis that may lead to the release of radionuclides. In addition, the release and transport of radionuclides have been analysed in several "what if"-type reviews. These cases are not directly related to the events identified by the performance analysis. Instead, they are used to test things such as the effects of the deterioration or loss of individual safety functions on the operation of the final disposal system.

The groundwater flow simulation underlying the radionuclide release and transport analyses has been repeated for ten different fissure network realisations. In the release and transport calculations, it thus is possible to distinguish the uncertainty resulting from the inherent heterogeneity of the rock from the uncertainty associated with the parameter data.

The effects of glacial cycles on groundwater flow have been taken into account in all radionuclide release and transport calculations. This is accomplished by varying the flows of the release paths by a time-dependent factor determined using a transient flow model prepared over the glacial cycle.

8.5 MODELLING

The performance assessment and radionuclide release analysis are based on numerical modelling by computer. The models used are based on the best scientific data and, whenever possible, also on-site research on the properties of the bedrock and surface environment at Olkiluoto. The purpose of the modelling is to determine whether the requirements for the long-term safety of final disposal are met in the cases considered. Therefore the most important results of the calculation are the figures for which the limits on the radiation exposure from the final disposal are set in the regulation. These so-called evaluation variables are the following:

1. radioactive releases from the bedrock to the biosphere, i.e. average radionuclide release rates. These are calculated for all release scenarios and compared with the maximum values in Guide YVL D.5.
2. annual radiation doses to humans during the first 10,000 years.
3. dose rates for plants and animals, these too only for releases during the first 10,000 years.

The first of these is derived from the modelling of the underground final disposal system, which describes the following, for example:

- groundwater flow and pressure,
- the temperature evolution of the different parts of the system,
- chemical changes in the groundwater, rock and technical release barriers,
- release of radionuclides from the low and intermediate level waste disposal repository
- release of radionuclides from spent nuclear fuel, taking into account their location in the fuel and in the parts of the protective cover,
- release of radionuclides from the canister and transport in technical release barriers to water-conducting fissures in the bedrock
- transport of radionuclides in the bedrock through its fissures, taking into account the variability of flow paths.

The radioactive releases are initial data for separate biosphere models which describe things like the spread of radionuclides in the surface environment, the metabolism of organisms and their exposure to radiation. Bedrock and biosphere modelling are also performed independently, so the result from a single calculation for one underground part can be used as initial data for biosphere models corresponding to several alternative ground surface conditions. Biosphere modelling results in radiation-dose-related evaluation variables 2 and 3.

Most cases are analysed deterministically, with each analysis being based on individual initial parameter values. In addition, the behavior of the final disposal system is also examined by probability-based sensitivity analysis (PSA). This analyses each case with a large number of calculations in which the initial parameters are varied randomly according to statistical distributions specific to each parameter. Numerous simulations can be used to statistically assess the uncertainties associated with the results and the sensitivity of the results to variability in the initial data.

8.6 ANALYSIS RESULTS

8.6.1 PERFORMANCE ANALYSIS

8.6.1.1 THE EXCAVATION AND BACKFILL PHASE

Groundwater flows increase from the pre-construction situation approximately hundredfold in the area of the disposal repositories, but return close to pre-excavation values after closure. When the disposal repositories are open, the average salinity of the groundwater around the repositories is in the same range as in the pre-construction phase, but increased flow may locally result in more dilute or salty conditions.

However, the changes remain in a region favourable for the functioning of the buffer and backfilling. The concentrations of the main corrosive substances in the canister, oxygen and sulfide, also remain in line with the target characteristics.

According to the temperature modelling, the maximum surface temperature of the canister is 95 °C when the buffer is dry and 75 °C when the buffer is saturated with groundwater. 40 years after placing the canister in the deposition hole, the maximum temperature of the rock in the wall of the hole is around 65 °C. Temperatures thus remain within the performance targets.

Excavation causes the formation of a damaged zone in the rock, especially on the tunnel floor, but a continuous zone of damage (which could act as a pathway for radionuclides) is not expected to form. The excavation damage zone and associated uncertainties are taken into account in flow and drift modelling.

A small rise of the buffer to the tunnel backfill is expected in those cases where the deposition hole becomes saturated much faster than the backfill above it. In addition, it is possible that due to mechanical erosion, the buffer mass may to some extent move inside the buffer and from the buffer to the backfill. Overall, the buffer mass losses caused by these processes remain so small that the buffer is able to achieve sufficient, designed integrity as the saturation progresses.

The consumption of oxygen remaining in the deposition tunnels in the backfill and buffer is relatively rapid under both unsaturated and saturated conditions, as it reacts with pyrite and other minerals. Reductive chemical conditions advantageous for long-term safety are thus quickly achieved around the canisters, in the buffer and in the backfill. Alkaline solutions extracted from the cement materials used in construction may affect the backfill locally, but the amounts of cement solutions transported up to the buffer are estimated to be small. The corrosion depth of the canisters caused by oxygen from the atmosphere and originally left in the premises is expected to be less than 2 millimetres.

However, based on current data, it can be estimated that the probability of having more than one initially defective canister in the disposal repository is less than 1%.

The conclusion of the performance assessment of the excavation and backfill phases is that the characteristics of the system will meet the performance targets at the end of the operating phase.

8.6.1.2 THE 10,000 YEARS FROM CLOSURE

For the next 10,000 years, the climate at Olkiluoto will remain temperate and the vegetation a coniferous forest in the temperate zone. Groundwater flow and chemistry recover from the disturbances caused by excavation. The most important processes are the absorption of water into the clays of the buffer, backfill and containment structures and the consequent increase in expansion pressure and homogenisation of the structure, as well as the reduction of residual heat from the radioactive decay of spent nuclear fuel.

Land upheaval continues, but it depends on climate development how long it takes before the seashore is so far away that subsequent changes will no longer affect flows in the final disposal volume; this can take from one thousand to ten thousand years. The residual heat output of the spent nuclear fuel placed in final disposal will decrease to a very low level in a few thousand years.

The salinity of groundwater at the final disposal depth recovers from the changes caused by excavation significantly more slowly than the flow of groundwater. At the final disposal depth, the groundwater generally remains weakly alkaline (pH around 7.5) and chemically reductive, but the weathering of the cement structures increases the pH locally. The salinity, chloride ion content and total cation concentration, which are significant for buffer performance, decrease slowly as rainwater seeps into groundwater. However, the concentrations remain in line with the target characteristics.

Groundwater flowing into the disposal repository causes buffer and backfill to saturate and build up pressure. The initial differences in density are evened out, although they do not disappear completely. The full saturation of the buffer is calculated to take from some tens of years to several thousand years, depending on the location. The expansion of the buffer to the backfill and the resulting changes in buffer density are so small that the performance targets for buffer and backfill are not compromised.

During the period of elevated temperature caused by the residual heat of spent nuclear fuel, the geochemical changes in the buffer from interaction with groundwater are negligible. No significant changes to minerals are expected. The chemical properties of groundwater remain within the target limits, and microbial sulfide production in the buffer is low at most. The chemistry of the backfill pore water develops in the same way as in the buffer, but is less affected by the heat from the spent nuclear fuel. The disturbances caused by solutions extracted from the cement and the corrosion products of metals are calculated to be insignificant. Local sulfide production due to sulphate-reducing microbes is possible in low-density regions, and has been considered in the canister corrosion review.

Calculations taking into account groundwater flow, sulfide production and the potential early course of buffer development show that corrosion of the copper canister is very low during the first 10,000 years. The canisters remain intact in all the load cases considered.

The performance assessment for the period after the closure of the disposal repository concludes that the technical release barriers and the bedrock properties are in line with the performance targets for the first 10,000 years, with the exception of deviations. Such deviations include higher-than-aimed flow at a deposition hole and groundwater composition in a few deposition holes and in a low-density range in the backfill where the reduction of sulphate to sulfide is possible.

8.6.1.3 DEVELOPMENT UNTIL THE END OF THE TEMPERATE CLIMATE PERIOD

After the first 10,000 to 15,000 years, the Olkiluoto area and its environs have joined the mainland and become inland. The final disposal system as a whole has reached a state where the technical release barriers are considered to have reached the intended properties. This is especially true for the expanding-clay components, the most important of which are the buffer and backfill. In addition to the fact that their water conductivities have essentially reached the required very low state, the canisters are not subjected to significant flows of substances detrimental to the performance of the copper; the dense porous structure of the buffer itself prevents the development of sulfide-forming microbial strains. Overall, the development during the temperate period is very slow, characterised by a gradual dilution of the groundwater chemistry, which in some deposition holes may reach a state favourable to chemical erosion towards the very end of the temperate period. The physical factors associated with chemical erosion are poorly understood, so the related description combines both the data obtained from laboratory experiments and in part the computational estimates parameterised based on them. In particular, data on the interaction between groundwater in the nearby rock and the expanding clay used in the buffer are incomplete. As a result, data that are believed to be strongly conservative have been used in the computational estimates. This means that the model estimates are very likely to overestimate the intensity of chemical erosion of the buffer. As a result of the overestimated calculations obtained in this way, it is found that the buffer may lose its effectiveness in a small number of deposition holes.

The first lost performance target is sufficient tightness to prevent microbial activity in the buffer, after which the microbes are able to produce sulfide from the sulphate dissolved in the buffer's porous water by means of dissolved organic substances used as energy sources. The concentration of sulfide thus produced is controlled by the ferrous minerals present, especially goethite. As long as the buffer, despite microbial activity, is sufficiently dense to prevent the flow of water, the canister will not be subjected to a flow of corrosive substances that would violate its integrity, although corrosion of copper is possible to some extent.

Eventually, at least in those deposition holes that are subject to strong groundwater flow, erosion will progress to the point where the safety functions provided by the buffer cease completely. In this kind of case, corrosion can progress through the entire copper cladding and radionuclides are released into the bedrock. Although corrosion can break a maximum of around 3% of the canisters in a million years – much longer than the duration of the temperate phase before the next cold climate phase – the resulting flows of radioactivity into the biosphere do not exceed regulatory limits. It should be further noted that in the expected development scenario, the number of canisters to break will be much lower.

8.6.1.4 THE NEXT PERMAFROST AND GLACIER PHASE

As the climate cools, precipitation decreases to such an extent that even the evaporation reduced due to the cooling can keep the ground surface free of a year-round snow cover. Under such conditions, as the climate continues to cool, the earth begins to freeze. As the water conductivity of the frozen earth also decreases very sharply, the groundwater flow is much slower in the permafrost phase than in the temperate and more rainy climatic phase. At the same time, this means that the groundwater circulation is also unable to transport substances harmful to the underground final disposal system. As the cold climate phase continues, permafrost penetrates deeper and deeper into the rock. However, it has been estimated that a cold climate with a sufficiently low temperature and sufficiently long duration for the permafrost to progress to the final disposal depth is very unlikely in the Olkiluoto area.

During the permafrost phase, deep rock conditions are very stable and are particularly favourable for the long-term safety of final disposal. As the cold climate phase continues, the retreat of the permafrost will be preceded by the arrival of inland ice in the Olkiluoto area. The progress of the ice is driven by a growing mass of ice, fed by the snow falling on the back of the glacier, far from the edge of the ice. So much water is bound to the ice globally that the amount of water in the seas is declining significantly, and continental areas have expanded widely around the globe. As the thick ice approaches Olkiluoto, the mechanical state of the rock begins to change. Under thick ice, the earth's crust "flexes" downward. The subsidence of the earth's crust under the ice results in the crust rising a good distance in front of the inland ice. During this so-called "fore bulge" phase, the first earthquakes induced directly by inland ice may develop, but are not expected to be particularly severe.

Ice arrives on top of the cold earth. As the ice thickens, its bottom eventually melts, because the ice effectively isolates the ground surface from the cold air. For this reason, geothermal heat generation is eventually enough to raise the rock temperature above the freezing point of the water. Eventually the ice bottom also melts, and the ice is said to be warm-bottomed at that point. The thickening of the ice is of great importance for the mechanical state of the final disposal rock; the state of tension on the canisters becomes strong. However, this has been prepared for in the design of the canisters. The canisters are dimensioned to maintain their integrity even in a state of tension produced by very thick ice. However, it is possible that despite the high reliability of quality assurance, a small number of initially defective, cracked canisters have been disposed of in (random) deposition holes exposed to a high state of stress. In this case, due to so-called strain aging, the inner part may become brittle and the canister will lose its strength against breakage.

Although the water pressure under the thick warm-bottomed ice is very high, the pressure differences are very small. As a result, no significant groundwater flow can occur. After thousands of years, the climate will begin to warm, which will inevitably eventually lead to a retreat of inland ice from the Olkiluoto area. As the crust of the area has sunk hundreds of metres due to the weight of the ice, once it retreats, the Olkiluoto area is under a thick body of water, of which a significant part is melting water. The thick layer of water floats the melting ice, as a result of which the rock cannot be subjected to the pressure differences produced by the melting ice. Thus the groundwater flow remains very weak compared to the temperate climate phase. The change produced by a warming climate through the retreat of ice is also causing a rapid change in the mechanical stress state of the rock, to which the earth's crust responds by beginning to rise again. In the initial phase, the rise is very fast (currently around 6 mm per year in the Olkiluoto area). Such a state of severe change is considered to be conducive to severe earthquakes. Severe earthquakes occur in large deformation zones, from which a seismic wave propagates all over the surrounding rock. In a single rock fissure, a seismic wave produces a rock motion whose amplitude depends directly on the size of the fissure. With a low probability, it is possible that a single deposition hole will be intersected by a gap large enough that the rock movement induced in it will exceed 5 cm. In this case, it is possible that the canister will lose its integrity and radioactivity will be released into the bedrock. However, based on a computational estimate, the number of canisters that break in this way is so small that the resulting flow of radioactivity into the biosphere does not exceed regulatory limits.

The development of groundwater chemistry in stagnant stages of groundwater flow, permafrost, glacier and (in the case of Olkiluoto) in the water basin stage subsequent to thawing, is uncertain. As the development trend of groundwater chemistry during temperate climate phases is modelled towards more dilute conditions, the Olkiluoto area is apparently affected by some process that is able to restore groundwater chemistry conditions over the ice age cycle(s). Although the mass transfers produced by diffusion are able to even out the differences in groundwater concentration between different rock layers, diffusion itself is known to be very slow for a process of mass transfer. Nevertheless, although the root cause of the phenomenon is not known, Olkiluoto's current rock groundwater with its very strong ionic strength is considered such convincing evidence of the existence of a groundwater chemistry recovery process that the performance assessment assumes that the chemical conditions of the Olkiluoto groundwater will recover during the ice age cycle. Although the process of water chemistry recovery may also have an effect during the temperate climate phase, it can only become dominant under conditions in which the groundwater flows produced by pressure differences practically disappear.

8.6.1.5 DURING RECURRENT GLACIAL CYCLES

In the very long run, the most important factor in the performance analysis is the variability of climatic conditions. The alternation of temperate and cool climates, or glacial cycles, is expected to continue at the same level as in the last million years. The analysis assumes that the current temperate season will continue for 50,000 years, followed by repetitions of the last ice age, permafrost formation, glaciation and finally the thawing of the glacier after about 80,000 years, followed by new glaciation after around 90 years and ending approximately 145,000 years from now.

During temperate climates, the salinity of groundwater continues to decline slowly as rainwater and surface water seep deeper. At the end of this period, a few per cent of the canister locations may contain groundwater classified as dilute, i.e. containing few dissolved ions.

The most significant effect of pre-glacial permafrost formation on the disposal repositories is that it significantly slows down the infiltration of surface waters into groundwater, and the decline in salinity at the final disposal depth almost ceases. Permafrost is not expected to reach the final disposal depth, but the buffer and backfill are nevertheless expected to withstand freeze-thaw cycles without compromising safety functions.

At the end of the ice age, the permafrost melts and fresh meltwater seeps from the retreating glacier into the bedrock. The flow of groundwater then depends on the location of the edge of the glacier in relation to the disposal repository. When the facilities are still under the glacier and close to the edge, the flow can increase significantly and head downwards. Later, as the edge of the glacier passes the site, the main direction of flow is upward, and the flows decrease as the edge of the glacier recedes. For some deposition holes, higher groundwater flows and lower transport resistances than the target characteristics may occur during these phases, which has been taken into account in the assessment of canister corrosion and in the definition of radionuclide release scenarios.

Depending on the duration of the meltwater intrusion, dilute (low-salt) groundwater may be present at some canister locations. On the other hand, there are no indications that dilute meltwater has reached the final disposal depth at Olkiluoto during or before the previous glacial cycle. Other geochemical properties are also expected to match the target characteristics during the retreat and melting of the glacier.

The end of the ice age is also associated with a somewhat increased chance of earthquakes, as the earth's crust recovers after the glacier that weighed it down is gone. During the first glacial cycle, the probability of an earthquake causing a canister to break is still low. By selecting the locations of the deposition holes outside the large deformation zones and by avoiding the intersection of long fissures in the deposition holes, the risk of canisters breaking as a result of rock movement is reduced.

Sulfide is the main cause of corrosion of copper capsules. The transport of sulfide in the vicinity of a canister has been evaluated under different conditions. The results show that the total depth of corrosion will not exceed a few millimetres over a million years when the buffer operates as planned. Uncertainties related to the results have been identified and analysed in the form of scenarios. However, some canisters may break over a period of one million years, but based on simple biosphere studies, doses nevertheless remain very low: for the most exposed person, less than 10% of the annual radiation dose received by the average Finn.

In conclusion, after the first glacial cycle (more than 100,000 years after the closure of the facilities), the technical release barriers and the bedrock characteristics still meet the performance targets and target characteristics, with only some random deviations.

The characteristics of the technical release barriers and the bedrock over the million-year review period are still in line with the performance targets and target characteristics, with the exception of the developments mentioned above.

8.6.2 RADIONUCLIDE RELEASE SCENARIOS

8.6.2.1 BASELINE SCENARIO

The baseline scenario assumes that the performance targets for the release barriers of the disposal repository will be met. In this situation, within one million years, radionuclides will only be released from the low and intermediate level waste disposal repository. In the baseline comparison case, the nuclides controlling the release rate vary depending on the time period considered. Mo-93 is a significant nuclide in the early moments after the closure of the facilities, as it is poorly retained in the backfill material of the low and intermediate level waste disposal repository. Significant nuclides at later times are first Ni-59, and then Ra-226 in the distant future.

Figure 8-3 shows the normalised release rates of radionuclides from the low and intermediate level waste disposal repository as a function of time. The standardised release rates are calculated by dividing the radionuclide-specific release rates by the maximum release rate values given in Guide YVL D.5. The regulatory requirement is met when the standardised release rate is less than one. According to the graph, the standardised release rates are at most around one millionth of the upper limit set.

Unlikely developments leading to the release of radionuclides have been identified in the performance analysis as an unusually high isostatic load on the canisters; possible significant rock movement; and canister corrosion due to chemical erosion of the buffer. In all calculation cases, the release rates from the bedrock are at least an order of magnitude lower than the upper release rate limit according to Guide YVL D.5. The most significant nuclides in releases from the spent fuel disposal repository are I-129, Cl-36 and Ra-226. Ra-226 is the most significant nuclide for releases in the case of erosion-corrosion, and in other cases it also dominates releases in the vicinity, but releases from the bedrock have been strongly attenuated thanks to effective containment.

The key results of biosphere modelling are the projection of the evolution of the surface environment over the 10,000 years following final disposal, as well as the annual radiation doses to humans, plants and animals. In the current biosphere assessment, the individual doses per route of exposure, radionuclide and site form a dose distribution of the population that identifies the average individual dose in a family or small village community exposed to the highest radiation exposure and the average individual dose in the rest of the exposed population. Typical absorbed doses are calculated for plants and animals. The results of the baseline reference case are summarised below and in more detail in the preliminary safety report submitted to STUK.

Radiation doses to humans

In the baseline case, releases only from the low and intermediate level waste repository, the screening analysis of the released radionuclides identified three radiologically relevant nuclides for which detailed modelling was performed: Mo-93, Ag-108m and Sr-90. Figure 8-4 shows the average individual dose in a family or small village community exposed to the greatest radiation exposure. The average individual dose to the rest of the exposed population behaves similarly over time, but is approximately two orders of magnitude lower. The individual dose representing the group with the highest radiation exposure is at most 6x10-12 mSv (approximately 1,300 years after the closure of the disposal repository), and the average individual dose to the rest of the exposed population is at most 5x10-14 mSv (approximately 1,300 years after the closure). These results are one hundred thousandths and one millionths below the set radiation dose limits

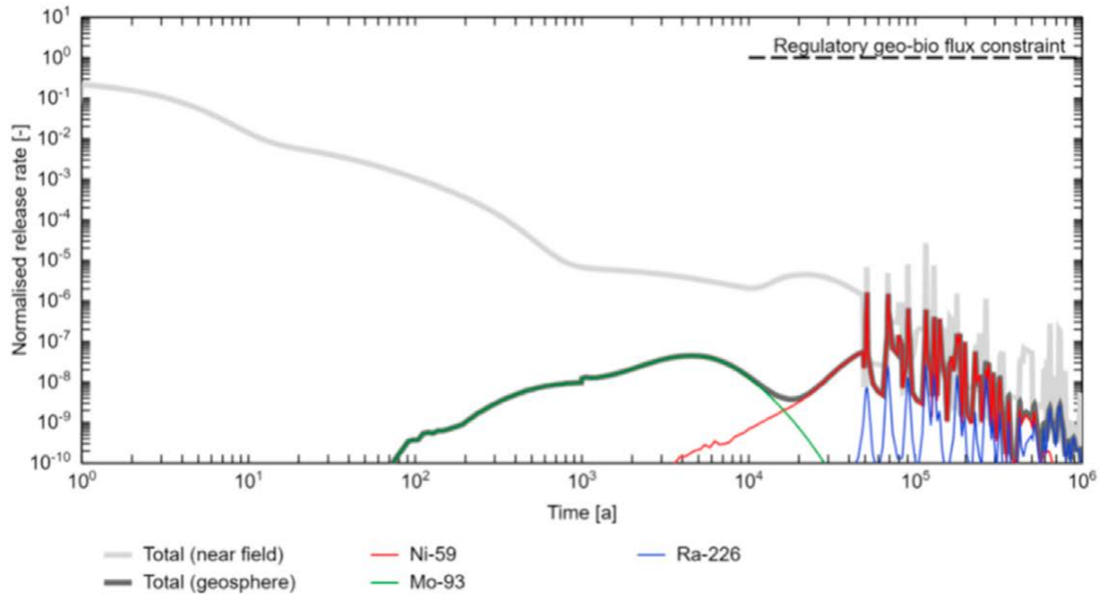


Figure 8-3. Standardised radioactive release rates from the vicinity (grey curve) and bedrock **(black curve)** in the reference case of the baseline scenario. The figure also shows the nuclides with the highest standardised release rates. The release rate of each radionuclide is standardised by a nuclide-specific limit value set by the authorities for the release rate of radioactivity from the bedrock to the biosphere.

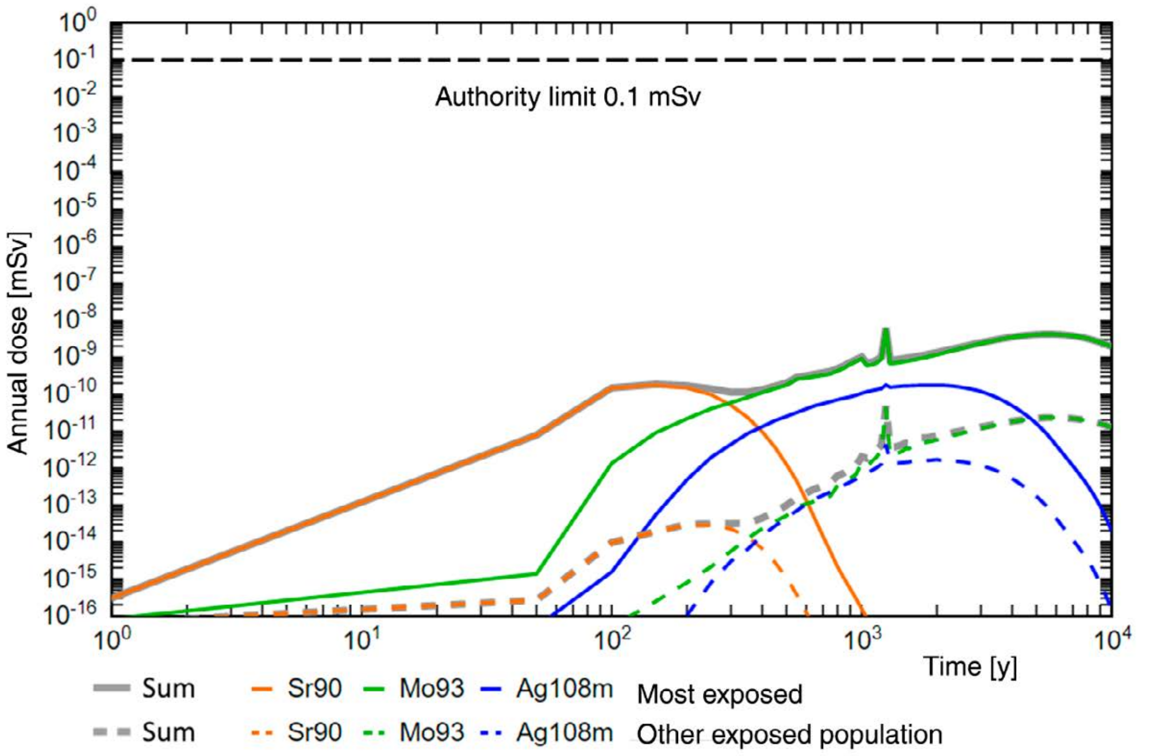


Figure 8-4. Average individual dose to the most exposed family or small village community and to the other exposed population, as well as the proportions of radionuclides in the baseline case after the closure of the disposal repository.

(Figure 8-3). In practice, the releases of Mo-93, Ag-108m and Sr-90 determine the magnitude of the radiation doses in the reference case.

Radiation doses to plants and animals

Typical absorbed doses are calculated for plants and animals. In the baseline scenario, the highest typical dose rate (average absorbed dose rate weighted according to the surface areas of contaminated habitats suitable for each organism) of 5.9x10-10 µGy/h occurs approximately 1,200 years after the closure of the disposal repository to Marenzelleria mud worms. This is several orders of magnitude below the reference value of 10 µGy/h proposed by the international ERICA and PROTECT projects. The same is the case for the other 45 reviewed plant and animal species representing the terrestrial and aquatic ecosystems around Olkiluoto.

8.6.2.2 UNLIKELY DEVELOPMENTS LEADING TO RELEASES FROM THE SPENT FUEL DISPOSAL REPOSITORY

Developments leading to releases identified in the performance analysis affect the integrity of the canisters during different time periods. Unusually high isostatic stress is possible during the ice age maximum. Rock movement is most likely to occur during the retreat phase of glaciation. Chemical erosion and consequent corrosion of the canisters can lead to canisters breaking at different times, but the development of conditions leading to chemical erosion first requires prolonged infiltration of dilute water into the deposition holes.

The effects of a single canister breaking due to isostatic stress have been estimated by assuming that the canister breaks at the maximum point of the first ice age (Global warming (RCP 4.5)), 60,000 years after the closure of the repository (calculation case GB-CC). The model's uncertainties have been mapped by varying the water chemistry (GB-Brackish, GB-Fresh, GB-Dilute), the groundwater flow scaling factor (GB-LOVAR, GB-HIVAR) and the flow canalisation (GB-CHAN), as well as the aleatory uncertainty associated with rock heterogeneity by placing the breaking canister in all the deposition holes approved by RSC (GB-ALLOC2). The most significant nuclides in these cases are I-129, Cl-36 and Ra-226. Of these, Ra-226 is strongly retained in the bedrock, making it a significant nuclide, mainly in terms of releases in the vicinity. Both in reference case GB-CC and in all alternative calculation cases, the standardised total release from the bedrock is more than two orders of magnitude below the release limit set in Guide YVL D.5.

In the baseline case, rock movement is assumed to cause the failure of one canister during the withdrawal phase of the first glacial period (Global warming, RCP 4.5), 68,000 years after the closure of the repository (GB-PG). The model's uncertainties have been elucidated in a calculation case where rock movement is assumed to reactivate cracks in the vicinity of the deposition hole and thus lead to an increase in flow (GB-PGNF). The effect of rock heterogeneity has been assessed by placing the breaking canister in all deposition holes intersected by a gap larger than 150 m (GB-ALLOC1). Release rates are dominated by the same nuclides as in the case of isostatic stress. Release from the bedrock is dominated by I-129 and Cl-36 and releases in the vicinity by Ra-226. In the case of one breaking canister, the maximum standardised release rate is approximately three orders of magnitude lower than the upper limit given in Guide YVL D.5. Based on the performance analysis, the maximum number of breaking canisters during rock movement could be 9 canisters. With this number of breaking canisters, the 5% and 95% percentage points for the standardised release rate are three and two orders of magnitude below the upper limit of the YVL Guide.

A canister breaking due to corrosion is the result of an increasing stream of sulfide to the canister surface as a result of buffer erosion. In the baseline case (GC-CC), chemical erosion is assumed to start when the cation concentration in the deposition hole is diluted, as a result of dilute water seeping from the surface, to the reference level defined in the performance analysis (8 meq/l). In this case, the number of canisters that break in one million years is 41. The model's uncertainties have been taken into account by calculating cases where a more cautious cation concentration limit is used for the onset of erosion (12 meq/l, GC-C1), as well as a thinner copper corrosion thickness (GC-C2). In these cases, the number of breaking canisters is 72 and 140. The above case of GC-C2 has been further complemented by transport in bentonite colloids (GC-C2BEN), the transport of colloids possibly formed from the fuel (GC-C2INT) and the strong canalisation of flow in the bedrock (GC-C2CHAN). Consideration of colloids has little effect on release rates from the bedrock. The release rates from the bedrock are highest in GC-C2CHAN-related cases. The maximum standardised release rate is approximately one order of magnitude lower than the upper limit of Guide YVL D.5. The most significant nuclides in most cases are Ra-226, I-121 and Cl-36.

8.6.2.3 "WHAT IF" CASES

The "what if" calculation cases examine the deterioration of individual safety functions. The calculation cases are divided into five different groups, of which one examines the safety functions of the low and intermediate level waste disposal repository. Four groups of calculation cases look at the spent fuel final disposal repository. In these hypothetical calculation cases, canister breakage is not based on defined developments, but deterioration of safety functions is expected to result in canister breakage within a few hundred years (G1 cases, canister(s) expected to break 300 years from now), a few thousand years (G2 cases, canister(s) expected to break from 1,000 to 10,000 years from now), a few tens of thousands of years (G3 cases, canister(s) expected to break 60,000 years from now) or a few hundred thousand years from now (G4 cases, canister(s) expected to break 300,000 years from now).

Only the breaking of a canister can lead to the release of radionuclides. Thus the ultimate assumption of "what if" cases is that one or more canisters will break within the selected time window for one reason or another. In the calculation cases, the simultaneous deterioration of several safety functions is also considered.

The cases to be considered are the particularly early breaking of the canister(s) during the current warm period (G1-CC, G1-Gas, G2-CC, G2-T2012) and a case where, in addition to the breaking of the canister, fuel and metal parts dissolve faster than expected (G1-FUEL, G1-FUEL2, G3-FUEL, G3-FUEL2), or in addition to the above, the performance of the buffer is impaired (G1-FUEL-BUF, G3-FUEL-BUF) or severely impaired (G1-FUEL-BUF2, G3- FUEL-BUF2). The breaking of several canisters at a later point in time is also considered in a separate calculation case (G4-ALLOC). For the low and intermediate level disposal repository, cases are considered where the concreting of the waste deteriorates faster than expected (GA-EBSRET, GA-HIFLOW, GA-NOBAS), the chemical conditions are different than expected (GA-GEOCHEM, GA-ISA) or the flow in the bedrock is strongly canalised (GA-GEOFLOW). By looking at releases to the vicinity and the bedrock separately, it is also possible to assess a situation where the bedrock has lost its ability to hinder the transport of nuclides (GA-CC, G1-CC, G2-CC, G3-CC, G4-CC).

In all cases, the maximum standardised release rate is at least one order of magnitude lower than the upper limit of Guide YVL D.5.

The release and transport of radionuclides have also been examined in probabilistic analyses. The review has covered releases from the low and intermediate level waste disposal repository and spent fuel disposal repository in release scenarios derived from performance analysis and involving isostatic loading and rock movement. Probability-based uncertainty and sensitivity analyses have examined the effects of both epistemic and aleatory uncertainties. A simplified bedrock description has been used in all probability-based calculation cases. Sufficient accuracy of the simplified bedrock model has been ensured by separate comparison cases.

The operation of the low and intermediate level waste disposal repository has been considered in three calculation cases: GA-PRBA (aleatory uncertainty related to groundwater flow), GA-PRBE (epistemic uncertainty related to parameters) and GA-PRBEA (combined aleatory and epistemic uncertainty). The calculation results for the low and intermediate level waste disposal repository are, in the uncertainty analysis, the standardised release rates from the bedrock to the biosphere and, in the sensitivity analysis, the dose rates using dose conversion factors for the use of well water as drinking water and mixing the release rate from the bedrock for 500 m3/a of water. The release rates based on the uncertainty analysis are in all calculation cases at least three to five or more orders of magnitude below the limits set by YVL Guide D.5. Based on the sensitivity analysis, the aleatory uncertainty calculation cases are sensitive to bedrock transport resistance, but not to water flow time, saturation time of the disposal repository or total flow through the disposal repository. For epistemic uncertainties, the most important ones were the distribution coefficients of strontium, americium and plutonium in the bedrock. Even in cases of combined aleatory and epistemic uncertainty, each individual iteration of the calculation case fell below the release rate limits set by Guide YVL D.5 and the dose limit of 0.1 mSv/a.

The release of radionuclides from the spent fuel disposal repository has been examined by probabilistic modelling in four calculation cases: epistemic uncertainty in the case of a canister breaking due to isostatic stress (GB-PRB1); epistemic and aleatory uncertainty in the case of a canister breaking due to isostatic stress (GB-PRB2); epistemic and aleatory uncertainty in the case of a canister breaking due to rock movement (GB-PRB3); and epistemic and aleatory uncertainty in the case of a canister breaking and buffer and rock disturbance due to rock movement (GB-PRB4). The probability-based calculations have been performed for one canister, but post-processing of the results has also examined the probability-based cases of failure of the largest number of canisters identified in PAFOS analyses: three canisters under isostatic load, and nine canisters as a result of rock movement.

Based on the sensitivity analysis, in both developments leading to canisters breaking, the release rates from the bedrock are the most sensitive to aleatory uncertainties about the groundwater transport time and transport resistance on the release paths. The most significant epistemic uncertainties about the release of radionuclides due to isostatic loading and rock movement are related to the corrosion rate of the protective cover; the dissolution rate of the fuel matrix; the IRF proportions of iodine and chlorine; and the retention properties of these nuclides in the bedrock. The sorption properties of radium in the bedrock will be among the most significant uncertainties if rock movement is assumed to degrade buffer characteristics and increase groundwater flow in the vicinity of the deposition hole and in the bedrock.

In the analyses related to release caused by isostatic stress, no single realisation of the calculation case led to the release rate limit set by Guide YVL D.5 being exceeded. The 95% uncertainty limit for the results for the standardised maximum release rate is below the Guide YVL D.5 limit by more than two orders of magnitude. In the case of rock movement, the 95% uncertainty limit for the standardised maximum release rate is below the YVL D.5 limit value by an order of magnitude. Here too, no single realisation of the calculation case led to the release rate limit set by Guide YVL D.5 being exceeded.

8.6.2.4 SUMMARY

Figure 8-5 shows the maximum bedrock radioactive releases obtained from the scenario analysis and their timing in relation to the release limits set by the authorities.

The meeting of the requirements is examined in the long-term safety case prepared for the licence application. It finds that the annual radiation doses resulting from developments that are considered likely will remain clearly below the limit provided in the Government Decree over the course of the next 10,000 years, even for the most exposed people, and the doses incurred by other people will remain negligible. It is estimated that, after this time, the releases of radioactive substances resulting from developments that are considered unlikely will at most remain at approximately one tenth of the maximum values specified by STUK. Based on an assessment of typical radiation doses, the radiation exposure of the current fauna of the final disposal site will remain clearly under the reference value proposed in international projects. The resulting radiation doses and release rates of radioactive substances have been assessed taking into account the possible random deviations from the operability requirements for the final disposal system as well as the uncertainties in the calculation models and initial data used in the assessment.

The conclusions presented above are justified in detail in the long-term safety case documentation submitted to STUK.

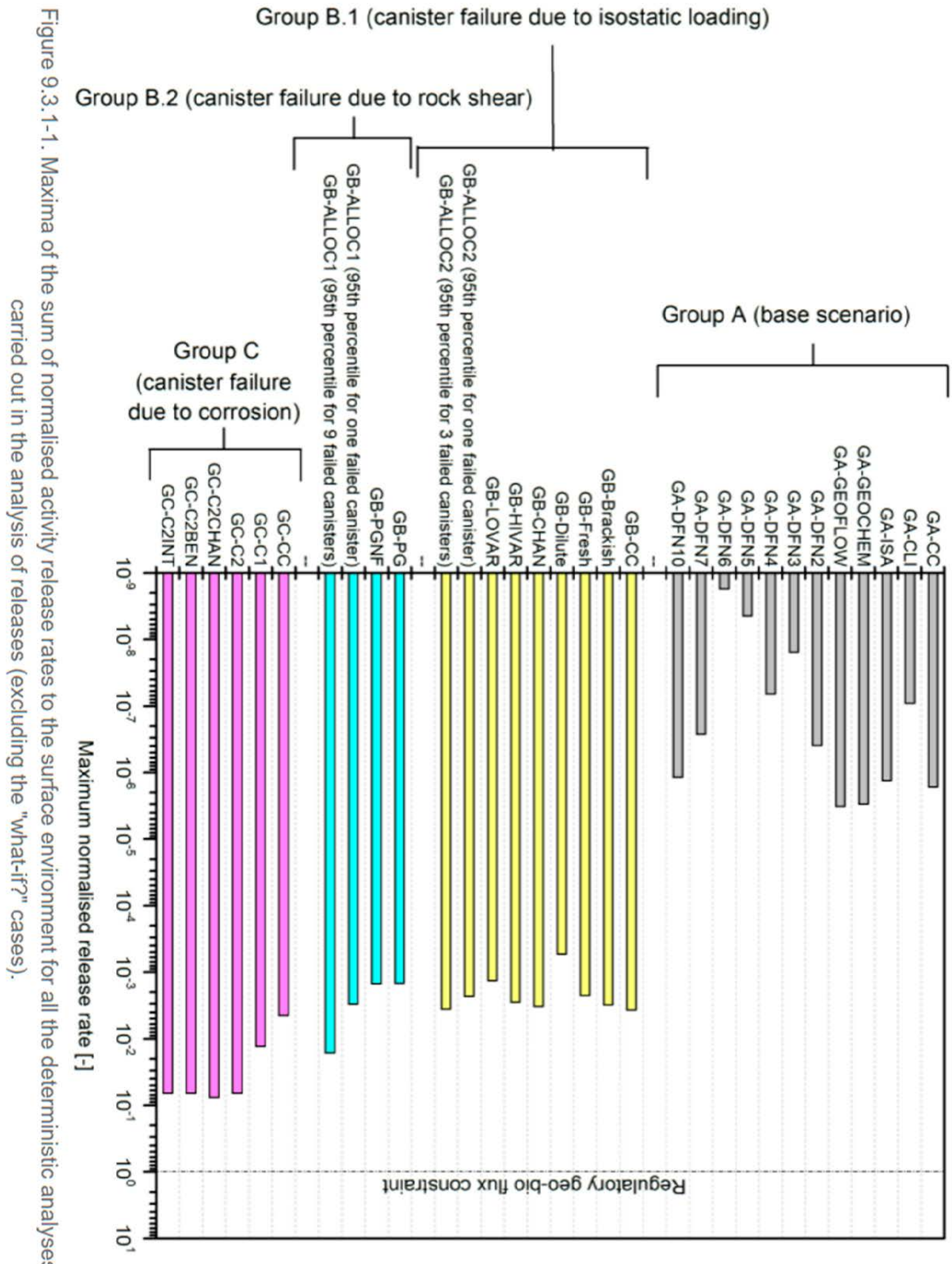


Figure 8-5. The maximum bedrock radioactive releases from the different calculation cases obtained from the scenario analysis and their timing in relation to the release limits set by the authorities.

8.7 ESTIMATE OF THE SAFETY OF THE FINAL DISPOSAL SOLUTION

The long-term safety of final disposal is comprehensively assessed in the full-scale TURVA-2020 safety case completed in 2021, which sup-ports the application for an operating licence for the disposal facility to be submitted in the same year. Compliance with the requirements relat-ed to long-term safety has been assessed in the safety case's perfor-mance assessment and dose calculations. The safety case shows that both high-level spent fuel and low and intermediate level waste can be placed safely at Olkiluoto in accordance with the related requirements (laws and guidelines). The safety case is also considered to be at a level sufficient for the operating licence application. The safety case also presents the uncertainties related to long-term safety assessment at Olkiluoto. The safety case also includes a section assessing future safe-ty assessments and discussing how to further reduce uncertainties and promote optimisation in research and development.

8.8 DEVELOPMENT PLANS

According to the Nuclear Energy Act, the safety of final disposal after the granting of an operating licence is assessed at least every 15 years in connection with periodic safety assessments, which are submitted to STUK for approval. Posiva's plans are also presented in the nuclear waste management plans (YJH programmes), which describe the nuclear waste management plans and development targets every three years. The YJH programmes are submitted to the Ministry of Economic Affairs and Employment.

9 INFORMATION ON POSSIBLE ENVIRONMENTAL IMPACTS CROSSING THE BORDERS OF FINLAND

The only possible functions or measures that may have an impact on other countries relate to radionuclide emissions from the final disposal of spent nuclear fuel. Even in the immediate vicinity of the final disposal area, doses resulting from postulated operational occurrences and accidents will remain lower than the required limit value. In neighbouring countries, doses would be lower by several orders of magnitude; the distance from Olkiluoto to the Swedish mainland, for example, is more than 200 kilometres. The project is not expected to have significant adverse cross-border environmental impacts under any circumstances.

10 HARM PREVENTION AND MITIGATION

During the design and environmental impact assessment work on the encapsulation plant and disposal facility, the possibilities of preventing, limiting or mitigating the adverse effects of the project by means of design or implementation have been explored. For the duration of the final disposal operations, environmental monitoring and radiation control programmes have been prepared to monitor the effects of the final disposal on the environment. The expected effects of the final disposal activity on the environment are minor.

10.1 DESIGN BASES OF RADIATION PROTECTION

During any period reviewed, final disposal must not give rise to health or environmental effects in excess of the maximum levels considered acceptable at the time of implementing final disposal. The encapsulation plant and disposal facility shall be designed in such a way that the radiation effects resulting from the developments considered probable do not exceed the limit values indicated above.

Limiting the release of radioactive substances

The operation of the encapsulation plant and disposal facility, as well as its structures and systems, shall be designed in such a way that the release of radioactive substances into the facility and the environment is prevented or limited by all practical means. The facility has systems in place to recover radioactive materials released into treatment facilities; clean the surfaces of radioactive materials released to them; and properly treat and pack the accumulated radioactive waste.

The premises of the facility in the air of which significant quantities of radioactive substances may be released are equipped with ventilation and filtration systems designed to:

- reduce the concentration of radioactive substances in these facilities;
- prevent the spread of radioactive materials into other premises of the facility;
- prevent the release of radioactive material into the environment.

These ventilation and filtration systems also operate at their designed capacity in the event of an anticipated operational occurrence or a postulated accident.

The design of the ventilation systems of the encapsulation plant and disposal facility follows Guide YVL B.1, “Safety design of a nuclear power plant”, as applicable.

Limitation of employees’ radiation exposure

Work spaces and passageways in regular use at the encapsulation plant and disposal facility shall be designed and located so that the dose rate of external radiation and the risk of internal radiation exposure are minimised. Structures, systems and equipment containing significant amounts of radioactive material are located in their own rooms or protected effectively. Radiation protection is designed with sufficient safety margins. In addition, many of the functions are remote controlled.

The spaces of the encapsulation plant and disposal facility are classified based on the estimated radiation conditions. Facilities requiring supervision from the point of view of radiation protection are located in their own area, to which access may be restricted and supervised in an appropriate manner. The arrangements for the radiation controlled areas of underground facilities take into account the specific characteristics of these facilities and the work to be carried out there. For the operation, inspection and maintenance of the equipment, the conditions and circumstances shall be designed in such a way that the number and duration of work steps to be carried out under radiation is kept to a minimum.

Radiation monitoring uses personal measuring devices equipped with alarms, so that no one is unknowingly exposed to significant radiation doses during the operation of the encapsulation plant and disposal facility.

The design of the radiation protection arrangements at the encapsulation plant and disposal facility follows the instructions in the C series of the Nuclear Safety Guidelines.

Radiation monitoring

The purpose of radiation monitoring is to prevent humans, animals and the environment from receiving significant radiation doses by monitoring radiation and activity levels. The main source of airborne radioactivity in the disposal facility is assumed to be radon seeping into rock spaces. In addition to radon, personnel receive radiation doses from final disposal canisters.

In the encapsulation plant, the main sources of radioactivity are the handling of the transport container and transfer cask; the encapsulation of fuel elements; and maintenance and repair work.

The radioactivity of the exhaust air in the radiation controlled area is measured continuously. If radioactivity from spent nuclear fuel is detected in the air, the exhaust ventilation is stopped and the source of the radiation leak is identified. The exhaust air from the canister storage space and canister shaft of the disposal repository is recirculated through the ventilation of the radiation controlled area of the canister shaft and encapsulation plant. If the radon concentration in the air at the disposal facility exceeds the permitted limit, ventilation power will be increased.

In practice, people can receive radiation doses from direct radiation coming from the transfer cask and the final disposal canister, and not therefore as a result of emissions. This means that the transfer route of the final disposal canister forms an area where the presence and movement of people are recorded and the radiation doses received are reliably measured. In practice, such an area is separated into its own closed area: a radiation controlled area which is accessed through a control point. The radiation doses received by staff and visitors are recorded at the control point.

There is no need to separate the runoff coming from radiation controlled area of the disposal repository and the runoff coming from the non-controlled area, as it is highly certain that there is no contamination in the runoff.

10.2 PREVENTION OF OPERATIONAL OCCURRENCES AND ACCIDENTS; CONSEQUENCE MANAGEMENT

Preparations have been made for operational occurrences and accidents in the design of the encapsulation plant and disposal facility. Accident prevention is the guiding principle in all the activities of the plant.

Compliance with the safety requirements for the disturbance-free operation of the encapsulation plant and disposal facility shall be demonstrated by analyses and verified during the test operation of the facility. Where possible, the functionality of safety systems designed for operational occurrences and accidents shall also be verified during the test operation. The requirements for the test operation are presented in Guide YVL A.5, “Construction and commissioning of a nuclear facility”.

Compliance with the safety regulations for expected operational occurrences and postulated accidents is demonstrated by analyses that take into account the nature and severity of the different types of operational occurrences and accidents that may occur at the encapsulation plant and disposal facility. It is also essential for the representativeness of these events that the events that most limit the function and dimensioning of each safety system be analysed. Compliance with safety requirements is primarily demonstrated by deterministic safety analyses. These analyses will be presented in connection with the final safety report.

Prevention of damage to canisters

The manufacture, filling and sealing of the canisters is subject to a quality assurance and inspection programme to ensure that the final disposal canisters are intact and tight when transferred to the disposal repository and that they meet the requirements set for them in other respects.

The final disposal of the canisters takes place in premises classified as radiation controlled, while the construction of the disposal repository takes place in an area that is not radiation controlled. The controlled and non-controlled area are physically separated, and the transport of goods and materials to them takes place along different routes.

Sufficient safety distances to dampen vibration from excavation shall be left between the tunnels to be excavated and the deposition tunnels containing canisters. Building materials, machinery, explosives and quarry material are transported through the driving tunnel. The backfill materials for the deposition holes and tunnels are transported through the driving tunnel.

The final disposal canisters are transported through the canister shaft. The transfer of the canisters from the ground surface to the disposal depth takes place reliably with a single fault-tolerant canister lift. Reliability, availability and safety are ensured by the maintenance and periodic tests required for nuclear facilities and by preparing for imaginable accident scenarios.

Criticality accident prevention

The formation of fuel concentrations where an uncontrolled fission chain reaction maintained by neutrons is possible is prevented by structural solutions.

The transfer casks, storage facilities and handling equipment for spent fuel elements, as well as the canisters, shall be designed so that no critical fuel concentrations are formed under any operating situation, including anticipated operational occurrences and postulated accidents. Canisters that have been placed in final disposal will maintain their subcriticality even in the long term in situations where the internal structures of the canister are corroded and filled with groundwater. The assumptions of the criticality safety calculations (e.g. degree of enrichment of fuel, discharge burnup, safety margin for the effective growth factor) are chosen conservatively.

Prevention of fire and explosion hazards

The encapsulation plant and disposal facility shall be designed so that the probability of a fire is low and the consequences of the fire for safety are slight. Explosions that could jeopardise the integrity of fuel elements, canisters, equipment or facilities containing radioactive materials are also reliably prevented.

The objectives of the fire safety planning of the encapsulation plant and disposal facility are:

- to prevent fires;
- to detect and extinguish fires quickly;
- to prevent the spread of fires to premises where it could jeopardise the safety of the handling or storage of spent nuclear fuel;
- to minimise explosion hazards.

In the encapsulation plant and disposal facility, fire and explosion prevention is primarily based on space design and fire compartmentation. The materials used are generally non-combustible and heat resistant. Materials or equipment which increase the fire load or present a risk of ignition and explosion shall not be unnecessarily placed in or in the immediate vicinity of fire compartments critical for safety. Premises with significant fire load concentrations are separated into their own fire compartments.

The encapsulation plant and disposal facility will be equipped with an automatic fire alarm system designed to locate the fire with sufficient accuracy. In addition, the facility premises will be equipped, if necessary, with an extinguishing system suitable for the site and first-aid firefighting equipment suitable for operational fire protection. The fire alarm and extinguishing systems will also work effectively in the event of anticipated operational occurrences and postulated accidents. The design of fire safety arrangements has followed Guide YVL B.8, “Fire protection at a nuclear facility”.

The explosives used in rock construction are stored above ground in their own protected storage facilities. No more explosives than permitted shall be transported at one time, and the explosives depots shall be located in such a way that a possible explosion does not endanger the radiation safety of the disposal facility. Explosives are transported from the ground surface to the disposal repository by a different route or at a different time than radioactive materials. The kind of explosive is also often used whose ingredients are safe by themselves and are only mixed into an explosive combination at the blast site. In excavation work, a sufficient safety distance is always left between the blasting site and the deposition tunnels containing final disposal canisters.

10.3 TAKING EXTERNAL EVENTS INTO ACCOUNT IN DESIGN

The design of the encapsulation plant and disposal facility has taken into account the impacts resulting from natural phenomena and other events external to the plant that are considered to be possible. Natural phenomena to be considered include at least lightning, earthquakes, storm winds, floods and exceptional outdoor temperatures. Other events external to the plant to be considered include electromagnetic disturbances, airplane crash, wildfire and explosion.

10.4 LONG-TERM SAFETY

The principles of long-term safety and a summary of the related analyses and results are presented in Chapter 8 of this report.

10.5 MANAGING THE IMPACT OF SPENT NUCLEAR FUEL TRANSPORTS

The transportation of spent nuclear fuel during the operation of the encapsulation plant and disposal facility is subject to a separate licence, and the necessary licences for the transportation of nuclear materials and nuclear waste in Finland are issued by STUK. The transport cannot be commenced until STUK has ascertained that the transport equipment and transport arrangements and the arrangements for physical protection and emergency planning meet the requirements set for them and provision has been made for indemnification regarding liability in case of nuclear damage *(Nuclear Energy Decree, Section 56, Section 115).* Detailed regulations concerning transport safety, arrangements for physical protection and emergency planning and supervision are set out in Guide YVL D.2, "Transport of nuclear materials and nuclear waste". High requirements have been set for the transport packaging, its handling, preparedness for accidents, and documentation. The transport packaging must not lose its radiation protection properties even in the worst conceivable accident. During transportation, the spent nuclear fuel inside the transport packaging must remain subcritical under all conditions. The transport packaging is subject to stricter requirements than usual in exceptional situations.

The purpose of the provisions on the transportation of radioactive materials is to ensure the safety of transportation in such a way that the transport packaging used in each case adequately protects the environment and the substances carried, so that the environment is not exposed to loads higher than the permitted radiation dose. The provisions on a so-called type B(U) container based on the International Atomic Energy Agency's guidelines for the safe transport of radioactive material *(IAEA 2018 "Regulations for the safe transport of radioactive material", SSR-6)* apply to the transport packaging of spent nuclear fuel. The type of packaging used for transport must withstand tests to ensure the suitability of the container type for the transport of spent nuclear fuel.

For normal transport, it is required that the radiation dose rate at a distance of one metre from the outer surface of the packaging must not exceed 0.1 mSv/hour, and at the surface 2 mSv/hour. In addition, the packaging and the nuclear fuel transported inside it must be able to withstand the fatigue load caused by the vibrations normally generated during transport. The temperature of the transport environment is also important for the probability of damage to the materials. During transportation, the ambient temperature must not be too low. In normal transport, only a very small leakage flow into the environment is allowed from the packaging. According to the IAEA's requirements, the transport packaging must be able to withstand, during routine conditions of transport:

- a water spray for one hour;
- a drop from a height of 0.3 to 1.2 metres onto an immovable surface;
- a compressive load equivalent to 5 times the weight of the packaging;
- a penetration test where a 6 kg steel bar is dropped from a height of one metre towards the side wall of the packaging.

The radioactivity due to the surface contamination of the packaging (radioactive substances possibly on the surface of the packaging) may not exceed 4 Bq/cm^2 and, in terms of certain radionuclides, 0.4 Bq/cm^2.

In exceptional scenarios, the spent nuclear fuel transport packaging must meet significantly more stringent requirements. Among other things, it must withstand:

- a drop onto an immovable surface at the most unfavourable angle of impact from a height of nine metres;
- a drop onto a steel bar 0.15 m in diameter from a height of one metre;
- exposure for at least 30 minutes to a fire with a flame temperature of at least 800 °C;
- immersion at a depth of 200 m for at least one hour.

The tests that are related to exceptional scenarios strive to cover the mechanical and thermal loads caused by potential accident situations, including impacts to the packaging caused by collisions and a fire in a vehicle transporting flammable liquids. In addition, it must be kept in mind that, in reality, the object is not immovable. In the nine-metre drop test, the transport packaging reaches a speed of almost 50 km/h at the moment of impact, which is also a possible collision speed with another vehicle or obstacle, even in practical accident situations. During transportation, the spent nuclear fuel inside the transport packaging must remain subcritical under all conditions.

Road transports are supervised and accompanied by the necessary escort personnel: drivers of warning vehicles, drivers of police vehicles and other necessary persons, such as a radiation protection technician. During passage through larger urban areas, several police patrols are needed for traffic control. When transporting spent nuclear fuel, the escort is also accompanied by security personnel. Transport speed limits are low. Other transport options are also controlled.

10.6 MANAGEMENT OF IMPACTS FROM EXCAVATION AND CRUSHING

The nuisance caused by noise and other disturbance during excavation and crushing in the vicinity of the encapsulation plant and disposal facility can be mitigated by scheduling the work steps for daytime. The quarry pile is used in crushing as noise protection. The crushing plant and quarry pile can be located so that there are no buildings left in the noise and dust areas.

The Olkiluoto seismic system has been used to measure the effects on the bedrock from the construction sites for the disposal facility and the encapsulation plant. The Olkiluoto seismic system has been used to measure the effects on the bedrock from the construction sites for the disposal facility and the encapsulation plant. The blasting at the construction site of the disposal facility has had a maximum magnitude of around ML=1.4. The excavation work for the encapsulation plant has had a maximum magnitude of around ML=1.5. At both construction sites, more than 99% of the blasts fall below magnitude ML=1.0, and 90% fall below ML=0.5.

The most significant findings have been excavation-induced micro-earthquakes in 2017 and 2018 at the disposal facility. The magnitude of the micro-earthquakes has been ML=-0.5 at most. Compared to the excavation blasts, the micro-earthquakes release around 1,000 times less energy. The results are reported regularly, and the information is submitted to the Radiation and Nuclear Safety Authority.

10.7 CONSTRUCTION OF SURFACE CONNECTIONS

The location of the opening of the driving tunnel and the upper end of the shafts has been chosen so that they are above the surface of the Korvensuo water basin and also sufficiently above sea level so that water will not flood the driving tunnel or shafts as a result of external disturbance. The location of the entrance has also taken into account existing power lines, transformer stations, water basins, pipelines, roads and the location of the potential final disposal area in the bedrock, so that the opening is optimally located in relation to them as well. In the bedrock, the driving tunnel is located in such a way that the zones of rock fracture are penetrated as little as possible and the studies necessary to characterise the desired rock areas can be carried out.

10.8 MANAGING THE EFFECTS OF THE ENCAPSULATION PLANT

The encapsulation plant has been designed in accordance with safety regulations so that the release of radioactive substances into the environment remains insignificant even in the event of operational occurrences or accidents. All work steps in the encapsulation plant are carried out safely without significant releases or radiation doses to personnel.

10.9 UNDERGROUND DISPOSAL REPOSITORY AND SAFETY DISTANCES FOR DEPOSITION TUNNELS

When constructing and closing the disposal repository, the aim is to preserve the original properties of the rock and to limit changes to the smallest possible area around tunnels and shafts. For example, rock is carefully excavated, keeping the disturbance zone caused by excavation as small as possible. In order to determine the extent of the disturbance zone, a method has been developed that can be used to monitor the actual quality of excavation (Mustonen et al. 2010). Water leaks are limited by avoiding water-conducting structures and by sealing leak points, for example by injection.

During the operating phase of the final disposal, when excavating the central and deposition tunnels, a sufficient safety distance is left between the excavation site and the deposition tunnels for work technical and general safety reasons. This way, the pressure wave from blasting discharged from the deposition tunnel to be excavated does not damage, for example, the wall between the radiation controlled area and the non-controlled area in the central tunnel. In addition, safety distances sufficient from a long-term safety perspective are left between the deposition tunnels and the research holes drilled in the bedrock.

10.10 CRITERIA FOR ASSESSING THE SUITABILITY OF THE FINAL DISPOSAL SITE

The properties required of the bedrock that acts as a natural release barrier at the final disposal site are recorded in STUK Regulation Y/4/2018 and Guide YVL D.5. The starting point for the recorded safety regulations is that the bedrock of the final disposal site must set and maintain favourable properties for the canister, buffer and deposition tunnel backfill systems. In addition, the bedrock must isolate the disposal facility from the effects of the surface environment and of human actions, while preventing or slowing down the spread of harmful substances into the surface environment. A final disposal site is not suitable for its purpose if it involves any factors that are clearly detrimental to long-term safety. Factors that suggest unsuitability of a final disposal site include the proximity of exploitable natural resources, exceptionally high tension inside the rock, high levels of seismic activity and conditions with exceptionally unfavourable groundwater characteristics.

The positioning of the spent nuclear fuel disposal facility is based on the avoidance of volumes delimited by structures of safety class CV2 determined on the basis of site investigations. The positioning of the disposal repositories to be constructed is guided by a rock classification based on site and safety studies and its suitability criteria. The suitability criteria affecting the positioning and design of the disposal repositories take into account, among other things, the natural fissures in the bedrock in different size classes and the water conductivity observed in the bedrock. The disposal facility and the positioning of the canisters will be designed so that the canisters are placed in intact rock volumes defined in the suitability classification, so that significant fragile structures located in the bedrock, or the high water conductivities associated with them, are not aligned with the placed canisters. In addition, the total area of the facility and the capsule distances are designed taking into account the heat transfer capacity of the bedrock and the residual heat capacity of the canisters, so that the temperature of the canisters does not exceed their specified limit value.

The construction of the different parts of the disposal repository will be carried out in stages, so that studies on the suitability of the rock volume planned for excavation and the preliminary classification of the rock will be carried out before the construction of that rock volume begins. The structure and properties of the rock surrounding the disposal repository that may be relevant to groundwater flow, rock movements or other issues important for long-term safety are identified and classified. The suitability classification of the rock will be refined during excavation and construction, and preparations will be made to change the location of the underground facilities if the quality of the rock surrounding the planned facilities proves to be significantly less favourable than in the design bases or the preliminary suitability assessment. Each final disposal canister containing spent nuclear fuel will only be placed in a rock volume and deposition hole approved by the suitability classification and meeting the suitability criteria.

10.11 CLOSURE OF THE DISPOSAL REPOSITORY AND UNDERGROUND DISPOSAL FACILITY

The deposition tunnels are backfilled and plugged after final disposal (installation of the canister and the buffer material), and the tunnel is backfilled in stages throughout the operation of the plant. Central tunnels and technical facilities will be closed as operational activity ceases in each area. At the end of the final disposal activity, the remaining central tunnels, vehicle connections and technical facilities as well as surface connections, such as the driving tunnel, shafts and open research holes, will be closed.

The clay and rock material used as materials for tunnel backfilling and plug structures, as well as concrete structures, prevent access to the final disposal area after the closure of the facilities. The properties of the materials used, such as low water conductivity and high durability deep in the bedrock, create favourable conditions for the technical release barriers used in final disposal. Low water conductivity prevents the tunnels from acting as a flow path to groundwater.

10.12 EFFECTS ON GROUNDWATER

Underground spaces are tightened with cement or silica injections, which keep the effects of the open tunnels on groundwater level to a minimum. Changes in pressure height are also limited by injecting separately defined leak points as efficiently as possible. Even large changes in local groundwater pressure height cannot be completely avoided, because even a small leak has caused and may cause large reductions in groundwater pressure, especially near ONKALO, but in some places also several hundred metres away. This is because the leaking structure is limited and has no connections to the rock sections that produce replacement water. The total amount of leaking water flows will also be limited by minimising the rock volumes open at any given time during the operating phase and by controlling the leakage of water from open facilities by injections. The positioning of the facilities is aimed at avoiding the features of the bedrock most liable to conduct water.

10.13 OVERSIGHT OF THE PLANT

During the operating phase, the encapsulation plant and disposal facility is divided into a monitored area, a radiation controlled area and a non-controlled area. Access to the radiation controlled area is controlled for reasons of radiation protection. All handling of spent fuel and final disposal canisters always takes place in the radiation controlled area. The encapsulation process will be monitored, underground facilities will be excavated and built and tunnels will be backfilled in the non-controlled area.

To keep the handling and installation conditions of the final disposal canisters clean, the ventilation in the controlled area is separated from the ventilation in the non-controlled area. The radioactivity of the exhaust air in the radiation controlled area is measured. In critical work steps, exhaust air filtration is switched on in advance. Radon exposure is followed by monitoring radon concentrations and adjusting ventilation volumes in all disposal repositories.

The purpose of access control is to find out who is working in the encapsulation plant and disposal facility at any given time, as well as to control access to both the controlled and the non-controlled area. In the case of radiation controlled facilities located deep in the bedrock, appropriate access control is not only a matter of radiation protection but also a matter of personal safety. Crossing the boundary between the controlled area and the non-controlled area underground is normally prohibited. However, moving from the controlled to the non-controlled area or the other way around is permitted in the event of an emergency, such as a fire.

The purpose of condition monitoring is to monitor the condition of the encapsulation plant and disposal facility and its systems during the operating phase. The condition of the encapsulation plant and disposal facility is monitored through measurements, periodic tests and inspections. The condition of the disposal repository is monitored by measuring the amount of leaking water, tension inside the rock and displacements in the disposal repository. The instrumentation system is also used to collect and process information on the condition of the disposal repository and ensure that occupational safety remains good in the disposal repository.

The Radiation and Nuclear Safety Authority oversees the safety of the handling, storage and final disposal of nuclear waste. To ensure proper planning for the final disposal of spent nuclear fuel, the authorities have imposed reporting obligations on nuclear waste producers. With the assistance of other expert organisations, the Radiation and Nuclear Safety Authority reviews the studies and technical plans for the safe final disposal of nuclear waste and provides feedback to the party implementing the project.

10.14 SOCIAL IMPACT

The aim is to reduce the social impact by minimising the already minor impact of the final disposal on bodies of water, recreational use and the landscape. The aim is to reduce uncertainty about safety through adequate dissemination of information.

11 FOLLOW-UP OF ENVIRONMENTAL IMPACTS OF THE PROJECT

11.1 LOAD AND IMPACT MONITORING DURING THE CONSTRUCTION AND OPERATION OF THE DISPOSAL FACILITY

Posiva is following up on the environmental impacts from the final disposal as part of the Olkiluoto Monitoring Programme (OMO) (Posiva 2021a), whose design takes into account the possible impacts on the environment that have been identified in this and previous impact assessments. The follow-up of environmental impacts aims at:

- producing information on the project's environmental impacts
- determining which changes result from project implementation
- determining the degree to which the impact assessment results correspond to reality
- determining how the mitigation of harm has succeeded
- initiating any necessary measures in case unforeseen significant harm occurs.

The Olkiluoto Monitoring Programme - 2022 (Posiva 2021a) serves as a detailed report on the monitoring programme presented in connection with the final safety report in accordance with the Radiation and Nuclear Safety Authority's Nuclear Safety Guide (YVL) D.5, 706, and meeting the requirements of the Radiation and Nuclear Safety Authority's Regulation Y/4/2018, Section 33, and the YVL Guide, Sections D.5, 506 and D.7, 829. The programme has been drawn up to verify the performance of release barriers. Its purpose is to ensure the suitability of the deposition location and the rock for final disposal and to collect safety-relevant information on the bedrock and the functioning of the release barriers. In addition, the programme will monitor the environmental impact of the Posiva project.

According to Guide YVL D.5, 506 f *(STUK 2018),* the monitoring programme must include monitoring of the surface environment. In addition, the Environmental Protection Act (527/2014) requires operators to be aware of the environmental impact of their operations. Especially with respect to the surface environment, the monitoring parameters and processes have been derived from the viewpoint of environmental impact assessment and monitoring, instead of that of long-term safety. In addition to the processes related to operational and long-term safety of the disposal facility, assessed under the Nuclear Energy Act *(990/1987),* the monitoring programme must collect information on the non-radiological environmental impacts of the project, monitored and assessed under the Environmental Protection Act *(527/2014).* Among other things, such impacts include processes that cause or can cause environmental impacts but have no significant effect on operational or long-term safety. The monitoring of the surface environment includes, for example, phenomena observed in the surface runoff and effluents from the underground facilities; phenomena related to the excavation, transportation, crushing and piling of rock material; and noise related to industrial activities. In addition, the monitoring of the surface environment also produces background information for other components of monitoring, for example regarding meteorological observations and land use. Soil groundwater levels; rock groundwater pressure and flows; and the chemical composition of groundwater are monitored as part of the hydrogeochemical, hydrological and hydrogeological monitoring. In addition, with respect to the environment, monitoring also includes other groundwater variables and the monitoring of bedrock stability.

11.1.1 EFFECTS OBSERVED SO FAR

The monitoring of environmental impacts as part of Posiva's monitoring programme has been underway since the beginning of the construction of ONKALO. The results of the monitoring so far and other observations and estimates are presented in more detail in Sections 6.3 and 6.4. In summary, it can be stated that although there have been significant changes in the pressure, flow and chemical composition of rock groundwater as the excavation of ONKALO has progressed, the effects on the surface environment or groundwater from an environmental point of view have been slight at most. The most recent monitoring results are presented in the reports *Haapalehto et al. 2020 , Sojakka et al. 2020 , Yli-Kaila et al. 20 20 and Vaittinen et al. 2020 .*

Based on the measurements, Olkiluoto's largest sources of noise are the operational nuclear power plants and traffic in Olkiluodontie, while the noise resulting from the construction of the encapsulation plant and disposal facility is only significant in a small area. The dust from the construction is visible in the analysis of the needle samples collected from Olkiluoto, but it does not seem to have any permanent effects *(Aro et al. 2018 a & b, Sojakka et al. 2019)*. In some measuring points near ONKALO, signs have been observed of a small decrease in the groundwater surface level that may be due to the flow of groundwater to ONKALO. However, no effect on the surface level in the boreholes in the eastern part of the island has been observed, for example.

11.1.2 FOLLOW-UP OF RADIATION EFFECTS

The tracking of radiation impacts is based on measurements of radioactive substance releases and concentrations as well as radiation dose rate measurements. Concentrations and dose rates are also assessed through calculations based on release and weather data, among others, because it is expected that radioactive substances originating from the facility cannot be observed in the environment due to their low quantity. The expected radiation impacts are so low that no particular population health tracking is considered necessary: it would not be possible to distinguish any health detriments from normal morbidity. If necessary, it is, however, possible to compare the health of the surrounding population to the population living further from the site by using the data maintained by the National Institute of Public Health, for example.

To obtain comparative data from different directions and distances, the monitoring of concentrations of radioactive substances and radiation dose rates is started already before final disposal activities. Concentrations are measured from air, water, soil, organisms, agricultural products, products gathered in the wild, and game. Weather data and other data necessary for assessing the calculated impacts will also be collected, as is currently being done.

Releases of radioactive substances into the environment will be measured at the final disposal stage. Typical measurement locations are the exhaust air and waste water outlets. The concentration and dose rate measurements that have been started will be continued.

11.1.3 FOLLOW-UP OF OTHER IMPACTS

The monitoring programme includes monitoring of the following non-radiation-related items to detect the environmental impact of the project:

- noise
- runoff from the dumping area and process water from ONKALO
- vegetation and animals
- amount and quality of well water
- groundwater surface level
- chemical composition of groundwater

In addition, many bedrock phenomena and characteristics such as groundwater chemistry, pressure height and flow; land upheaval and other movement in the earth's crust; and the amounts of foreign substances used in construction (TLTA) are all also monitored. However, changes to these do not have an immediate impact on the environment. Their study is primarily related to the monitoring of the maintenance of favourable conditions at the final disposal site and the assessment of long-term safety.

11.2 MONITORING AFTER CLOSURE

Posiva's monitoring measurements will end when the plant is closed in a manner approved by STUK, according to current plans in the 2120s. During the closure phase, Posiva will prepare a proposal for a post-closure monitoring programme and pay a lump sum to the Government. This amount will be used by the authorities for any monitoring and control they deem necessary. However, final disposal must be done in such a way that it is safe even without follow-up monitoring.

The monitoring of bedrock conditions has been investigated in several international projects. Post-closure monitoring may include, but is not limited to, measurement of radioactivity from the ground surface and from deep boreholes. The holes will also allow for monitoring groundwater level, flows, chemistry, temperature, etc. On the ground surface, geophysical measurements can be used for tracking the occurrence of micro earthquakes. Compromising the integrity of nuclear material by illegal means would require activity that is visible on the ground surface. This activity could be detected and monitored internationally via satellites, for example.

12 LITERATURE (ALL)

Aaltonen, I., Lahti, M., Engström, J., Mattila, J., Paananen, M., Paulamäki, S., Gehör, S., Kärki, A., Ahokas, T., Torvela, T., Font, K. 2010. Geological Model of the Olkiluoto Site, Version 2.0. Posiva Working Report 2010-70, pp. 51. Posiva Oy, Eurajoki, Finland.

Aaltonen, I. (ed.), Engström, J., Front, K., Gehör, S., Kosunen, P., Kärki, A., Paananen, M., Paulamäki, S., Mattila, J. 2016. Geology of Olkiluoto. Posiva-raportti 2016-16.

Ahjos, T. & Uski, M., 1992. Earthquakes in northern Europe in 1375-1989. Tectonophysics, 207:1-23. https://doi.org/10.1016/0040-1951(92)90469-M

Aho, J. 2008. Käytetyn ydinpolttoaineen turvallista loppusijoitusta koskeva informaatio ja luottamus Eurajoen kuntalaisten keskuudessa. Informaatiotutkimuksen pro gradu -työ. Tampereen yliopisto, Informaatiotutkimuksen laitos. Toukokuu 2008.

Alho, P., Sojakka, T. 2018. Summary of Breeding Bird Counts in the Olkiluoto Archipelago. Posiva Working Report 2017-08, 78 s.

Andersson, J., Ahokas, H., Hudson, J., Koskinen, L., Luukkonen, A., Löfman, J., Keto, V., Pitkänen, P., Mattila, J., Ikonen, A., Ylä-Mella, M. 2007. Olkiluoto Site Description 2006. Posiva Oy, Raportti 2007-03.

Aro, L., Lindroos, A-J., Rautio. P., Ryynänen, A., Korpela, L., Mäkinen, V., Viherä-Aarnio, A. & Salemaa, M. 2018a. Results of forest monitoring on Olkiluoto Island in 2015. Posiva Oy, Working Report 2016-55. 197 p.

Aro, L., Lindroos, A-J., Rautio, P., Ryynänen, A., Korpela, L., Viherä-Aarnio, A. & Salemaa, M. 2018b. Results of forest monitoring on Olkiluoto Island in 2016. Posiva Oy, Working Report 2017-28. 164 p.

Corporate Image Oy 2007. Kuntaimagotutkimus 2006. Posiva Oy, Työraportti 2007-73.

Eronen, M., Glückert, G., van de Plassche, O., van de Plicht, J., Rantala, P. 1995. Land uplift in the Olkiluoto-Pyhäjärvi area, southwestern Finland, during last 8000 years. Nuclear Waste Commission of Finnish Power Companies (YJT), Helsinki, Finland. Report YJT-95-17, 26 p.

Eurajoen kunta 2012. Tilastotietoa. [http://www.eurajoki.fi /html/fi /Tilastotietoa.html] (huhtikuu 2012)

Haapalehto, S., Malm, M., Kaisko, O., Lahtinen, S., Saaranen, V. 2021. Results of Monitoring at Olkiluoto in 2020, Rock Mechanics. Posiva Working Report 2021-47. Posiva Oy, Olkiluoto.

Haapanen, A. (ed.) 2011. Results of monitoring at Olkiluoto in 2010: Environment. Working Report 2011-45. Posiva Oy, Eurajoki, Finland. 154 p.

Haapanen, R., Aro, L., Helin, J., Hjerpe, T., Ikonen, A.T.K., Kirkkala, T., Koivunen, S., Lahdenperä, A-M., Puhakka, L., Rinne, M. & Salo, T. 2009. Olkiluoto Biosphere Description 2009. Posiva Report 2009–2, 416 p.

Haapanen, R., Aro, L., Ilvesniemi, H., Kareinen, T., Kirkkala, T., Lahdenperä, A-M., Mykrä, S., Turkki, H., Ikonen, A. 2007. Olkiluoto Biosphere Description 2006. Posiva Oy, Raportti 2007-02.

Helsingin Yliopisto 2012. Geotieteiden ja maantieteen laitos. [http://www.helsinki.fi /geo/seismo/maanjaristykset/suomi.html] (huhtikuu 2012)

Helsingin yliopisto 2007. Seismologian laitos. [http://www.seismo.helsinki.fi /index.htm].

Hirvonen, H., Lehtinen, A., Hatanpää, E. 2006. Results of Monitoring at Olkiluoto in 2005. Eurajoki, Finland, Posiva Oy. Working Report 2006-67. 174 p.

Hirvonen, H. & Mäntynen, M. (Ed.). 2005. Results of Monitoring at Olkiluoto in 2004 –Geochemistry.

Eurajoki, Finland. Posiva Oy. 74 p. Working Report 2005-29. 74 p.

ICRP 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. ICRP Annals of the ICRP. Volume 37 Nos. 2-4 2007.

Ikonen, K. 2007. Far-Field Thermal-Mechanical Response of One- and Two-Storey Repositories in Olkiluoto. Posiva Oy. Työraportti 2007-29.

Ikäheimonen T. K., 2002. Säteily ja sen havaitseminen, Suureet ja yksiköt. Säteilyturvakeskus.

Insinööritoimisto Paavo Ristola Oy & Ramboll Oy 2007a. Olkiluodon osayleiskaava, maisema- ja kulttuurihistoriaselvitys. 25.1.2007. 11 s. + liitteet.

Insinööritoimisto Paavo Ristola Oy & Ramboll Oy 2007b. Olkiluodon osayleiskaava, luonnon perustilaselvitys. 29.1.2007. 25 s. + liitteet.

Insinööritoimisto Paavo Ristola Oy 2006a. Olkiluodon meluselvitys 2006. Teollisuuden Voima Oy. 18.8.2006.

Insinööritoimisto Paavo Ristola Oy 2006b. Arviointi vaikutuksista Liiklankarin Natura 2000 -alueen luontoarvoihin. Teollisuuden Voima Oy. 12.12.2006.

ISUH (Institute of Seismology, University of Helsinki), 2019a. Final and preliminary bulletins in Nordic Format, http://www.seismo.helsinki.fi/bulletin/list/norBull.html , accessed 26.8.2019

ISUH (Institute of Seismology, University of Helsinki), 2019b. Catalog of earthquakes in Finland 1610 – 1999, http://www.seismo.helsinki.fi/bulletin/list/catalog/Suomi_n.html , accessed on 26.8.2019

Kaisko, O., Malm, M. 2019. Microearthquakes During the Construction and Excavation of the Final Repository for the Spent Nuclear Fuel at Olkiluoto in 2002-2018. Posiva Working Report 2012–05.

Kala- ja vesitutkimus Oy, Mikkola-Roos, M., Hirvonen, H. 1996. Toukolanranta. Rakentamisen vaikutukset. Ekologinen näkökulma II. Helsingin kaupunkisuunnitteluviraston julkaisuja 1996:20.

Kari, M., Kojo, M. & Litmanen, T. 2010. Community Divided: Adaptation and aversion towards the spent nuclear fuel repository in Eurajoki and its neighbouring municipalities. University of Jyväskylä and University of Tampere.

Karvonen, T. 2010. Prediction of Long-Term Influence of ONKALO and Korvensuo Reservoir on Groundwater Level and Water Balance Components on Olkiluoto Island. Posiva Working Report 2010-55.

Karvonen, T. P. 2020. Surface and Near-Surface Hydrological Modelling in Olkiluoto. Eurajoki, Finland, Posiva Oy. Posiva report 2019-02. 376 p.

Kasa, S. 2011. Results of Monitoring at Olkiluoto in 2009, Foreign materials. Posiva Working Report 2010-46.

Kirkkala, T. & Turkki, H. 2005. Rauman ja Eurajoen edustan merialue. Teoksessa: Sarvala, M. & Sarvala, J. (toim.) Miten voit, Selkämeri? Ympäristön tila Lounais-Suomessa. Lounais-Suomen ympäristökeskus, Turku. s. 48–65.

Kirkkomäki 2012. Loppusijoituksen asemointi ja vaiheittainen rakentaminen 2012. Posiva Oy, Työraportti 2012-69.

Klockars, J., Tammisto, E., Ahokas, H. 2007. Results of Monitoring at Olkiluoto in 2006– Hydrology. Posiva Oy, Working Report 2007-50.

Korhonen, K. T., Hirvelä, H., Lehtonen, A., Tuominen, S. Hyvönen, P., Balázs, A., Aro, L. 2016. State of the Forests on Olkiluoto Island in 2014. Posiva Oy, Working Report 2016-01.

Koskivirta, O. 2012. Käytetyn polttoaineen kuljettaminen Loviisan voimalaitokselta Eurajoen Olkiluotoon kapselointia ja loppusijoittamista varten - toteutustapaselvitys. Muistio YJÄTE/6/2012. Fortum Power and Heat Oy.

Kotola, J. & Nurminen, J. 2003. Kaupunkialueiden hydrologia valunnan ja ainehuuhtouman muodostuminen rakennetuilla alueilla, osa 2: koealuetutkimus. Teknillisen korkeakoulun vesitalouden ja vesirakennuksen julkaisuja 8. Espoo, 203 s.

Laakso, S., Kuisma, H., Kilpeläinen, P., Kostiainen, E. 2007. Käytetyn ydinpolttoaineen loppusijoituslaitoksen aluetaloudelliset, sosioekonomiset ja kunnallistaloudelliset vaikutukset. Kaupunkitutkimus TA Oy. Posiva Oy, Työraportti 2007-94.

Lahdenperä, A-M., Palmén, J., Hellä, P. 2005. Summary of Overburden Studies at Olkiluoto with an emphasis on Geosphere-Biosphere Interface. Posiva Oy, Työraportti 2005- 11.

Lahti, M. & Sirén, T. 2011. Results of Monitoring at Olkiluoto in 2010. Rock Mechanics. Posiva Working Report 2011-47.

Lahti, M. & Hakala, M. 2009. Results of Monitoring at Olkiluoto in 2010. Rock Mechanics. Posiva Working Report 2009-73.

Lahti, M. (ed.), Saari, J., Lakio, A., Kallio, U., Ahola, J., Koivula, H., Jokela, J., Poutanen, M. & Kemppainen, K. 2009. Results of Monitoring at Olkiluoto in 2008. Rock Mechanics. Posiva työraportti 2009-47.

Lamminmäki, T., Pitkänen, P., Penttinen, T., Pentti, E., Komulainen, J., Loimula, K., Wendling, L., Partamies, S. & Ahokas, T. P. 2017a. Results of Monitoring at Olkiluoto in 2015 Hydrogeochemistry. Eurajoki, Finland, Posiva Oy. Working report 2016-44. 332 p.

Lamminmäki, T., Pitkänen, P., Penttinen, T., Komulainen, J., Loimula, K., Wendling, L., Partamies, S., Ahokas, T. 2017b. Results of Monitoring at Olkiluoto in 2014 Hydrogeochemistry. Työraportti WR2015-44. Posiva Oy.

Liikennevirasto 2012. Liikennemääräkartta 2010. [http://portal.liikennevirasto.fi /portal/page/portal/f/liikennevirasto/tilastot/liikennemaarat/liikennemaarakartat/KVL_karttaVARELY_2011.pdf] (toukokuu 2012).

Litmanen, T., Kojo, M. & Kari, M. 2010. The rationality of acceptance in a nuclear community: analysing residents' opinions on the expansion of the SNF repository in the municipality of Eurajoki, Finland. Int.J.Nuclear Governance, Economy and Ecology, Vol. 3, No.1, 2010.

Loikkanen, M. 2007. Luotolinnustoinventointi Eurajoen Olkiluodossa 7.6.2007. Ramboll Finland Oy.

LT-Konsultit Oy 1998. Loppusijoituslaitoksen ympäristövaikutuksia. Posiva Oy. Työraportti 98-74.

Mattila, J. & Hakala, M. 2008. Results of monitoring at Olkiluoto in 2007. Rock mechanics. Posiva Working Report 2008-22.

Mattila, J. (ed.). 2007. Results of monitoring at Olkiluoto in 2006. Rock Mechanics. Posiva Working Report 2007-53.

Metsähallitus 2012. Kansallispuistot, Selkämeritietoa. [http://www.metsa.fi /sivustot/metsa/fi/luonnonsuojelu/suojelualueet/kansallispuistot/selkameritietoa/Sivut/Selkamerellesuunniteltukansallispuisto. aspx] (toukokuu 2012)

Minato, K., Ichimiya, M., Inoue, T. 2006. Research and Development Activities on Partitioning and Transmutation of Radioactive Nuclides in Japan. Actinide and Fission Product Partitioning and Transmutation. Ninth Information Exchange Meeting. Nîmes, France, 25-29 September 2006. OECD/NEA 2007. 750 p.

Museovirasto 2007. Rakennettu kulttuuriympäristö. Valtakunnallisesti merkittävät kulttuurihistorialliset ympäristöt 1993 -luettelo.

Mustonen, S., Norokallio, J., Mellanen, S., Lehtimäki, T. & Heikkinen, E. 2010. EDZ09 Project and Related EDZ Studies in ONKALO 2008 2010. Posiva Working Report 2010-27, 404 p.

Mönkkönen, H., Hakala, M., Paananen, M., Laine, E. 2012. ONKALO Rock Mechanics Model (RMM). Version 2.0. Working Report 2012-07.

NEA 2006. OECD/NEA, Advanced Fuel Cycles and Radioactive Waste Management. OECD 2006.

NEA 2002. OECD/NEA, Accelerator-driven Systems (ADS) and Fast Reactors in Advanced Fuel Cycles. Comparative Study. OECD 2002.

Nieminen, M., Ikonen, H., Koivunen, A. 2009. Small Mammals, Ants, Snails and Earthworms on the Island of Olkiluoto in 2009. Posiva working report 2009–112, 84 p.

Nieminen, M. & Saarikivi, J. 2008. Herpetofauna and Small Mammals on the Island of Olkiluoto in 2008. Posiva working report 2008–91, 39 p.

Niemi, M., Nieminen, M. 2018. Game Statistics for the Island of Olkiluoto in 2015-2016. Posiva Working Report 2016-54, 24s.

Paile, W. 2002. Säteilyn haittavaikutusten luokittelu. Kirjassa Säteilyn terveysvaikutukset.

Palomäki, J. 2021. FSAR Aihekohtainen raportti: Käytetyn polttoaineen kuljetukset Loviisasta Olkiluotoon kapselointia ja loppusijoittamista varten – toteutustapaselvitys.

Paunonen M. et al. 2016. Waste management of the encapsulation plant. Working report 2015-51.

Pere, T. (ed.), Sojakka, T., Aro, L., Lipping, T. 2017. Results of Monitoring at Olkiluoto in 2014 Environment. Työraportti 2015-45, Posiva Oy.

Pitkänen, P., Lamminmäki, T., Yli-Kaila, M., Penttinen, T., Tammisto, E., Vaittinen, T., Reijonen, H., Kietäväinen, R., Sahlstedt, E. & Partamies, S. 202X. Quality evaluation and explorative analysis of hydrochemical data of Olkiluoto site. Eurajoki, Finland, Posiva Oy. Posiva Report 2021-12. (in prep.).

Posiva SKB. 2017. KBS-3H System Design Phase 2011-2016: Final Report. Posiva SKB report 06. Posiva Oy, Eurajoki

Posiva 2005. Olkiluoto Site Description 2004 vol 3. POSIVA 2005-03, Olkiluoto, Finland: Posiva Oy 444 p.

Posiva 2009. Olkiluoto Site Description 2008. POSIVA 2009-01, Eurajoki, Finland: Posiva Oy 714 p.

Posiva 2021a. Olkiluodon monitorointiohjelma - 2022, Posiva-raportti 2020-02.

Posiva 2021b. Olkiluoto Site Description 2018. Posiva-raportti 2021-10.

Posiva 2021c. Sulfide Fluxes and Concentrations at The Olkiluto Site - 2021 Update. Työraportti 2021-07, Posiva Oy.

Posiva 2021d. POSIVA 2021-01. Safety Case for the Operating Licence Application – Synthesis. Posiva report 2021-01. Posiva Oy. Eurajoki, Finland

Posiva Oy 2012-01. Monitoring at Olkiluoto a programme for the period before repository operation. Report 2012-01. Posiva Oy, Eurajoki.

Posiva Oy 2012-10. Safety case for the spent nuclear fuel disposal at Olkiluoto - Biosphere Assessment BSA-2012 Report 2012-10. Posiva Oy, Eurajoki.

Posiva 2013. Olkiluoto Site Descpription 2011. Eurajoki, Finland, Posiva Oy. Posiva Report 2011-02. 1029p.

Posiva Oy 2012c. Safety Case Plan 2012. Posiva Oy Eurajoki.

Posiva Oy 2012d. Olkiluodon ja Loviisan voimalaitosten ydinjätehuolto Yhteenveto vuoden 2011 toiminnasta. 52 s.

Posiva Oy 2009. TKS-2009. Olkiluodon ja Loviisan voimalaitosten ydinjätehuolto: Selvitys suunnitelluista toimenpiteistä ja niiden valmistelusta vuosina 2010–2012. Posiva Oy.

Posiva Oy 2008. Safety Case Plan 2008. Posiva Oy, Raportti 2008-05.

Posiva Oy 2006. TKS-2006. Nuclear Waste Management of the Olkiluoto and Loviisa Power Plants: Programme for Research, Development and Technical Design for 2007-2009. Posiva Oy.

Posiva Oy 2003. TKS-2003. Nuclear Waste Management of the Olkiluoto and Loviisa Power Plants: Programme for Research, Development and Technical Design for 2004-2006. Posiva Oy.Pradel, P. 2006. French Fuel Cycle Strategy and Partitioning and Transmutation Programme. Actinide and Fission Product Partitioning and Transmutation. Ninth Information Exchange Meeting. Nîmes, France, 25-29 September, 2006. OECD/NEA 2007. 750 s.

Pulkkanen, V-M. & Nordman, H. 2011. Effects of Bedrock Fractures on Radionuclide Transport near a Vertical Deposition Hole for Spent Nuclear Fuel. Posiva raportti 2011-3. 74 p.

Pöyry Environment Oy 2008. Ydinjätteen loppusijoituslaitoksen laajentaminen. Teemahaastattelut Eurajoen asukkaille. Lokakuu 2008.

Raiko, E. & Nordman, H. 1999. Kemiallinen myrkyllisyys käytetyn ydinpolttoaineen loppusijoituksessa. Posiva Oy, Työraportti 99-18.

Ramboll Analytics Oy 2007. Olkiluodon meluselvitys 2007.

Ramboll Finland Oy 2008. Olkiluodon osayleiskaavan liikenneselvitys. 15.4.2008.

Ramboll Finland Oy 2007. Olkiluodon voimalaitosalueen asukas- ja työntekijäkysely.

Ramboll Oy 2007. Pikkuapollon esiintyminen Olkiluodon osayleiskaava alueella 2007.

Ramboll Oy 2014. Olkiluodon biodiversiteettiselvitys. Teollisuuden Voima Oyj (sisäinen dokumentti)

Ramboll Oy 2021. Ympäristövaikutusten arviointi (YVA-selosteen), Meluselvitys.

Rantataro, J. 2001. Akustis-seismiset tutkimukset Olkiluodon läheisellä merialueella vuonna 2000. Posiva Oy, Working Report 2001-11.

Riikonen, S. 2006. Results of monitoring at Olkiluoto in 2005. Rock Mechanics. Posiva Working Report 2006-66.

Riikonen, S. 2005. Results of monitoring at Olkiluoto in 2004. Rock Mechanics. Posiva Working Report 2005-30.

Räihä, T. 2021. FSAR aihekohtainen raportti: Kapselointilaitokselta ilmaan vapautuvista päästöistä aiheutuvien säteilyannosten arviointi, NUCL-4467,.

Saanio ym. 2012. Saanio T., Ikonen A., Keto P., Kirkkomäki T., Kukkola T., Nieminen J. & Raiko H. Loppusijoituslaitoksen suunnitelma 2012. Työraportti 2012-50. Posiva Oy.

Saari, J., 2003. Seismic Network at the Olkiluoto Site. Working Report 2003-37. Posiva Oy, Eurajoki, Finland, 41 p.

Haapalehto, S., Malm, M., Kaisko, O., Marila, S., Saaranen, V. 2020. Results of Monitoring at Olkiluoto in 2019, Rock Mechanics. Posiva Working Report 2020-47.

Haapalehto, S. (ed), Malm, M., Kaisko, O., Lahtinen, S., Saaranen, V. 2021. Results of Monitoring at Olkiluoto in 2020, Rock Mechanics. Posiva Working Report 2021-47.

Saramäki, J. & Korhonen, K. 2005. State of the Forests on Olkiluoto in 2004. Comparisons Between Olkiluoto and the Rest of Southwest Finland. Posiva working report 2005–39. 79 p.

SKB 2011. Long-term safety for the fi nal repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project. Svensk Kärnbränslehantering AB. March 2011. Technical Report TR-11-01.

Smith, K. 2016. Monitoring Radiation Effects in the Environment.

Smith, P., Neall, F., Snellman, M., Pastina, B., Nordman, H., Johnson, L., Hjerpe, T. 2007. Safety Assessment for a KBS-3H repository for spent nuclear fuel at Olkiluoto – Summary report. Posiva Oy, Raportti 2007-06.

Sojakka, T., Weckman, K., Lipping, T., Haavisto, F., Rinne, A. 2019. Results of Monitoring at Olkiluoto in 2017 - Environment. Working Report 2018-45, Posiva Oy, Eurajoki.

Sojakka, T., Alho, P., Lipping, T., Toivola, M., Haavisto, F. 2020. Results of Monitoring at Olkiluoto in 2019, Environment. Posiva-raportti 2020-45.

Sosiaali- ja terveysministeriö 1999. Ympäristövaikutusten arviointi. Ihmisiin kohdistuvat terveydelliset ja sosiaaliset vaikutukset. Oppaita 1999:1. 51 s.

Stakes 2012. Ihmisiin kohdistuvien vaikutusten arviointi -käsikirja. Terveyden ja hyvinvoinnin laitos. [http://info.stakes.fi /iva/FI/index.htm] (huhtikuu 2012)

STUK 2021a. Suomalaisen keskimääräinen säteilyannos. [https://www.stuk.fi/aiheet/mita-sateily-on/ihmisen-radioaktiivisuus/suomalaisen-keskimaarainen-sateilyannos] (9.9.2021)

STUK 2021b. Esimerkkejä säteilyannoksista [https://www.stuk.fi/aiheet/sateilyvaara/esimerkkeja-sateilyannoksista] (9.9.2021)

STUK 2021c. Ionisoiva säteily. [https://www.stuk.fi/aiheet/mita-sateily-on/ionisoiva-sateily] (9.9.2021)

STUK 2021d. Luonnon taustasäteily. [https://www.stuk.fi/aiheet/sateily-ymparistossa/luonnon-taustasateily] (9.9.2021)

STUK 2021f. Asuntojen radonia koskevat viitearvot ja määräykset. [https://www.stuk.fi/aiheet/radon/asuntojen-radonia-koskevat-viitearvot-ja-maaraykset] (9.9.2021)

STUK 2021f. Radon Suomessa. [https://www.stuk.fi/aiheet/radon/radon-suomessa] (9.9.2021)

STUK 2021g. Röntgentutkimukset. [https://www.stuk.fi/aiheet/sateily-terveydenhuollossa/rontgentutkimukset] (9.9.2021)

STUK. 2018. YVL-ohje D.5: Ydinjätteiden loppusijoitus. Säteilyturvakeskus, Helsinki.

STUK 2010. Ydinjätteiden loppusijoitus. Säteilyturvakeskus, Ohje YVL D.5, Luonnos 4, 22.9.2010.

STUK 2005. Säteilyn terveysvaikutukset. Esite.

Suolanen, V., Ilvonen, M., Rossi, J., Räty, A. 2021. FSAR Aihekohtainen raportti: Käytetyn ydinpolttoaineen kuljetusten riskiselvityksen päivitys Posivan käyttölupahakemusta varten. Tutkimusraportti VTT-R-01014-21.

Suolanen, V. 2012. Käytetyn ydinpolttoaineen kuljetusten riskienhallinta. VTT. Tutkimusraportti VTT-R-04653-12.

Suolanen, V., Lautkaski, R., Rossi, J., Nyman, T., Rosqvist, T., Sonninen, S. 2004. Käytetyn ydinpolttoaineen kuljetusriskitarkastelun päivitys. Posiva Oy. Posiva-raportti 2004-04.

Suomalaisten energia-asenteet 2011. Seurantatutkimustietoa suomalaisten suhtautumisesta energiapoliittisiin kysymyksiin 1983–2011. Tutkimusraportti 29.08.2011.

Taivainen, O. 2007. Olkiluodon voimalaitoksen jäähdytys-, prosessi- ja saniteettivesien tarkkailuohjelman tulosten raportti vuodelta 2006. Teollisuuden Voima Oy. 21 s.

Tamminen, P., Aro, L., Salemaa, M. 2007. Forest soil survey and mapping of vegetation nutrition on Olkiluoto Island. Results from the fi rst inventory on FEH plots. Posiva Oy, Työraportti 2007-78.

Tanskanen, J. 2009. Laitoskuvaus 2009. Loppusijoituslaitossuunnitelmien yhteenvetoraportti. Posiva Oy.

Työraportti 2009-123.

Tielaitos 1993. Asfaltti- ja murskausasemien melun leviäminen. Tielaitoksen selvityksiä 43/1993.

Tilastokeskus 2012. Kuntien avainluvut. [http://www.stat.fi /tup/kunnat/kuntatiedot/051.html] (huhtikuu 2012)

Tolppanen, P. 1998. Louhitun kiven käyttökohteet ja murskaus. Posiva Oy. Työraportti 98-40.

Tolppanen, P. & Kokko, M. 1998. Räjähdystarvikkeiden käyttö, varastointi ja kuljetus käytetyn polttoaineen loppusijoitustilojen louhinnassa. Posiva Oy, Työraportti 98 41.

TVO (Teollisuuden Voima Oyj) 2012. Säteilyseurannan tulokset vuodelta 2011, laboratoriotulosteet.

Tuomi, P., Lamminmäki, T., Pedersen, K., Miettinen, H., Bomberg, M., Bell, E., Bernier-Latmani, R. & Pitkänen, P. P. 2020. Conceptual Model of Microbial Effects on Hydrogeochemical Conditions at the Olkiluoto Site. Eurajoki, Finland, Posiva Oy. Posiva Report 2020-03. 278 p. www.posiva.fi

UNSCEAR 2008. United Nations Scientifi c Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation. UNSCEAR 2008. Report the General Assembly with Scientifi c Annexes. Volume II.

Vaittinen, T., Ahokas, H., Nummela, J., Pentti, E. & Paulamäki, S. P. 2020a. Hydrogeological Structure Model of the Olkiluoto Site in 2015. Eurajoki, Finland, Posiva Oy. Working report 2019-06. 443 p. www.posiva.fi

Vaittinen, T., Hurmerinta, E., Nummela, J., Pentti, E., Tammisto, E., Turku, J., Karvonen, T. 2020b. Results of Monitoring at Olkiluoto in 2019 - Hydrology and Hydrogeology. Working report 2020-43, Posiva Oy.

Vesterbacka, K. & Arvela, H. 1998. Käytetyn ydinpolttoaineen loppusijoituksesta ympäristöön pääsevän luonnon radonkaasun aiheuttamat säteilyannokset. Posiva Oy, Työraportti 98-62.

Vieno, T. & Ikonen, A. 2005. Plan for Safety Case of Spent Fuel Repository at Olkiluoto. Posiva Oy, Raportti 2005-01.

Viinikainen, T. 1998. Käytetyn ydinpolttoaineen loppusijoituksen sosiaaliset vaikutukset kuntalaisten näkökulmasta, haastattelututkimus. Yhdyskuntasuunnittelun tutkimus- ja koulutuskeskus, Teknillinen korkeakoulu, Kesäkuu 1998. Posiva Oy, Työraportti 1998-59.

VTT 2009. Katsaus ydinjätehuollon tilanteeseen Suomessa ja muissa maissa. VTT tiedotteita–Research Notes 2515. Helsinki 2009.

Väisäsvaara, J., Pöllänen, J. & Sokolnicki, M. 2008. Monitoring Measurements by Difference Flow Method During the Year 2006. Drillholes OL-KR1, OL-KR4, OL-KR7, OLKR8,OL-KR10, OL-KR14, OL-KR22, OL-KR22B, OL-KR27 and OL-KR28. Eurajoki, Finland: Posiva Oy. Working Report 2008-16. 394 p.

Yli-Kaila, M., Ylöstalo, R., Penttinen, T., Wichmann, A., Pulkkinen, P., Lamminmäki, T., Pitkänen, P. 2020. Results of Monitoring at Olkiluoto in 2019 – Hydrogeochemistry. Eurajoki, Finland, Posiva Oy. Working report 2020-44. 183p.

Ympäristöhallinnon karttapalvelu 2012. OIVA Ympäristö- ja paikkatietopalvelu asiantuntijoille. [http://wwwp2.ymparisto.fi /scripts/oiva.asp] (kesäkuu 2012)

Yrjölä 2009. Eurajoki Olkiluoto Birdlife Survey 2008. Posiva working report 2009-14. 76p.

11

UPDATED ANALYSIS OF THE RETRIEVABILITY OF THE SPENT NUCLEAR FUEL

Photo: Posiva Oy

1 INTRODUCTION

The purpose of final disposal is to isolate the radioactive materials contained in spent nuclear fuel from living nature in a final and safe manner. However, it is technically possible to retrieve the final disposal canisters, if necessary. The retrievability of the canisters to the ground surface has not been a particular starting point in the final disposal plans and, therefore, the plans do not include any characteristics that facilitate the possible retrieval of fuel. It is, however, possible that, in the future, it will become desirable to use a new kind of final disposal method or completely new technology for handling spent fuel, or to utilise or reuse the raw materials or energy stored in the final disposal material. At no point may retrievability compromise the long-term safety of final disposal.

Retrievability can be assessed by examining the characteristics of the final disposal plan. Based on the plans, the canisters can be retrieved from the disposal repository to the ground surface at all phases of the project. Final disposal will be implemented in phases and, during the operating phase and after the closure of the facilities, each work phase can be reversed.

This analysis of the retrievability of the canisters is primarily based on the KBS-3V concept in which the canisters are placed in vertical holes.

2 FINAL DISPOSAL TECHNOLOGY

The final disposal canisters are massive metal containers with a spheroidal graphite cast iron component inside and a 50 mm thick copper outer shell. Three different models of canisters have been designed, one for each type of fuel used by the Finnish plants currently in operation and under construction. Equivalent canisters can be designed for any new fuel types. The canister is mechanically very strong, and it has a very long service life. The operability target for the canister is that it maintains its seal for hundreds of thousands of years. The lid of the inner canister is mounted with a bolt, which makes it easier to open the canister.

The canisters are transported by lift from the encapsulation plant to the disposal repository located deep in the bedrock. The repository's connections to the ground surface comprise a driving tunnel and vertical shafts. The actual disposal repository comprises parallel deposition tunnels, which are connected via a central tunnel. The maximum length of the deposition tunnels is approximately 350 metres.

2.1 TUNNEL BACKFILL

At the backfill phase, the deposition tunnels are filled with a granular bentonite material. Once the deposition tunnel is filled, a concrete plug is constructed at the end of the tunnel, preventing the backfill material from expanding into the central tunnel. Once all the canisters have been placed in the deposition holes, the facilities at the final disposal level and vertical shafts will be filled. The starting sections of the deposition tunnels, i.e. the front of each deposition tunnel plug, the central tunnels and the central tunnel connections between them, will be filled with a mixture of crushed rock and bentonite. This filling material will be placed in the tunnel similarly to the backfilling of the deposition tunnels, taking into account the different volumes.

Surface plugs will be installed at the upper end of the driving tunnel. In the driving tunnel, the rock material filling will extend to a depth of nearly 10 metres. The first massive concrete plugs will be located below it. The length and exact location of the concrete plugs will be determined at the installation phase. Under the plugs, there will be a section filled with boulders and crushed rock, which will extend to a distance of 40–50 m in the tunnel. After this point, the tunnel will be filled either with crushed rock or a mixture of crushed rock and bentonite depending on the depth. The most significant structures that conduct water will be isolated using either mechanical or hydraulic plug structures, whose detailed planning will take place at the backfill phase. The same materials will be used for the shafts as for the driving tunnel. Surface plugs will be installed near the ground surface, and rock material or a mixture of crushed rock and bentonite will be used below them.

3 FACTORS AFFECTING THE RETRIEVABILITY OF CANISTERS

In this appendix to the operating licence application, the retrieval technology is described regarding three different scenarios:

- retrieval before the closure of the deposition hole
- retrieval after the closure of the deposition tunnel, and
- retrieval after the closure of all facilities.

All the other scenarios during the lifespan of the canisters and the disposal repository can be derived from these scenarios, and the relevant retrieval technology will be equivalent to one of the presented technologies.

Factors relevant in terms of retrievability include, among other things, the time of retrieval and the removal of the bentonite used as a sealing and filling material, as well as considering the canisters' increase in temperature and radioactive radiation at the different phases of retrieval.

3.1 BENTONITE

The bentonite blocks placed on the bottom of the deposition hole and on top of the final disposal canister are disc-shaped, and the edge blocks form a ring around the final disposal canister. Bentonite absorbs any moisture from the bedrock and strives to swell. Bentonite's properties vary depending on its degree of saturation with water and the swelling pressure that develops.

If the retrievability of final disposal canisters is desirable, it must be possible to remove the bentonite from around the canister in order not to damage the canister when it is lifted. Bentonite can be removed by using pressurised brine, which breaks the structure of bentonite. The resulting bentonite slurry can then be removed from the deposition hole by pumping. Should the bentonite be contaminated, the bentonite removed by pumping must be treated as radioactive waste.

3.2 TEMPERATURE

The spent nuclear fuel inside the canisters generates residual heat due to radioactive decay. The heat generation increases the temperature of the bentonite surrounding the canisters and the bedrock, as the resulting residual heat is conducted to the surrounding bedrock. The thermal conductivity of the canisters is more than 100 times higher compared to the surrounding filling material and bedrock, so the canister temperature will rise faster than that of the surrounding materials.

Positioning of the canisters in the disposal repository is planned such that the temperature of canisters does not exceed +100°C. The temperature of the canisters will reach its peak (at approx. +95°C) approximately 20 years from their placement in final disposal. The maximum temperature of the rock and filling materials of the disposal repository, approximately +65°C, will be reached in a little under a century. The increase in temperature will make the retrieval operation more difficult; work will be slower and the costs will be higher. It has been estimated that, with the current technology, work can take place when the air temperature remains below +70°C and rock temperature below +100°C. When working in hot conditions, the tunnel temperature can be conditioned to a suitable level through cooling and ventilation. Hot viscous substances can be handled and, for example, road paving equipment is used for handling substances that are hotter than the deposition tunnel backfill material. Experience in working at high temperatures is available from many locations, e.g. Southern Africa and Germany, where work at mines has taken place at temperatures exceeding +55°C. If necessary, remote-controlled equipment can be used in order to avoid working in hot conditions and near a radiating canister.

3.3 RADIATION

If the canister's surface dose rates are assumed to be the calculated average maximum values at the time of disposal, approx. 270 mSv/h of gamma radiation and 14 mSv/h of neutrons, the dose rates on the canister surface will be approximately 180 mSv/h and 9 mSv/h, respectively, ten years after the final disposal of the canister. After 100 years, the radiation levels will be approximately 20 and 1 mSv/h, respectively. After 1,000 years, the respective radiation levels will be approximately 0.5 and 0.3 mSv/h, and after 10,000 years the dose rate has reduced to slightly above 0.1 mSv/h. The effective dose incurred by a radiation worker must not be higher than 20 millisieverts per year, so working continuously next to the canister during the possible retrieval of the canister must be limited during the first centuries. The removal of bentonite will require working near the deposition hole. However, in this case, the brine used for the removal of bentonite will protect the workers from direct external radiation coming from the canister. Some of the work can be performed using remote-controlled equipment, which reduces the workers' radiation exposure. These tasks could include transfers of canisters, for example.

4 RETRIEVAL BEFORE THE CLOSURE OF THE DEPOSITION HOLE

In the initial situation, the scenario under review is that a canister is being lowered into a hole, or it may already have been lowered into the deposition hole, and the gripper has let go of the canister. At this point, the hole must have been validated in an inspection. If, however, it is found for any reason that the hole is not valid or the bentonite inside the hole is not properly installed, the canister can be lifted from the hole by using the canister transfer and installation vehicle. The canister has protrusions for lifting. Before the start of operation, retrieval will be tested in a joint functional test during which a canister is retrieved from the disposal facility's canister repository to the encapsulation plant.

If a decision is made to return a canister to the ground surface before the deposition hole backfill, the canister is transferred to the canister shaft lift with the canister transfer and installation vehicle and lifted directly into the encapsulation plant. Canister retrieval uses the same work stages as canister installation, but in reverse order. In this case, the premise is that the bentonite in the hole has not yet swelled and stuck to the canister.

5 RETRIEVAL AFTER THE CLOSURE OF THE DEPOSITION TUNNEL

During the operating phase of the repository, deposition tunnels are backfilled starting from the back of the tunnel as canisters are installed into the deposition holes. Once all the canisters have been installed into a deposition tunnel and the tunnel backfill has been completed, a concrete plug is constructed at the end of the tunnel. The operating phase of the repository will continue for a long time after the first tunnel is closed; approximately for 100 years. Thus, the operation of the repository is under way and the central tunnel is open.

If a decision is made to retrieve canisters during the operating phase of the repository, when the backfill of part of the deposition tunnels has been completed, the retrieval will involve opening the deposition tunnel, opening the deposition hole and removing the canister. The plug at the mouth of the deposition tunnel is dismantled, after which the tunnel is emptied gradually, only removing the backfill material from a section covering one deposition hole at a time.

After the backfill material is removed, the hole is opened and the canister is removed. Then, the backfill material is removed from a section covering another deposition hole, and so forth. It is also possible that some of the central tunnels have been backfilled during the operating phase. In this case, the central tunnel backfill material must also be removed before opening the deposition tunnels.

Methods used in the dismantling of concrete structures, such as hydraulic jackhammers, can be used for removing the concrete plug. The tunnel backfill material is removed with conventional excavators. When opening a deposition tunnel, the radioactivity of air and backfill material is constantly monitored. The removal of bentonite from deposition holes may be based on dissolving bentonite with brine, for example. The canister is removed from the hole by using the canister transfer and installation vehicle that was used for installing the canister into the hole (or similar equipment) and carried into the encapsulation plant by means of a lift.

6 RETRIEVAL AFTER THE CLOSURE OF ALL FACILITIES

If desirable, the canisters can also be retrieved to the ground surface after the closure of the disposal repository has been completed, i.e. after all the canisters have been placed in final disposal, the tunnels and shafts have been backfilled and the repository has been closed. At this point, the encapsulation plant will also have been decommissioned.

If necessary, a facility to replace the decommissioned encapsulation plant will be constructed on the ground surface in order to process the canisters for retrieval purposes. The disposal repository is opened using largely the same working methods that were used when constructing the repository. Instead of excavating the repository, the shafts and tunnels are opened by digging out the backfill material, dismantling the constructed plug structures and pumping out the groundwater. For shafts, it is also possible to raise bore new shafts instead of opening the old shafts. The auxiliary facilities and central tunnels will be opened to the necessary extent by means of excavating. Then, the construction of necessary structures and installation of systems will take place in the auxiliary facilities, central tunnels, driving tunnels and shafts in order to replace the structures and systems that existed during the final disposal operations. The air temperature will be higher compared to that during the final disposal operations. The effects that this has on states of strain must be considered in the construction. Once the facilities have been constructed, the opening of the deposition tunnels and canister removal will take place using the same technologies that would have been used for canister retrieval during the facilities' operating phase. The loading and transport of material can be made from a protected space, if necessary.

7 OPENING A CANISTER AND RETRIEVING THE FUEL

The opening of a canister and retrieval of fuel from the canister can be executed at the encapsulation plant by completing the encapsulation process in reverse order. The machining station at the encapsulation plant can be used for opening the top end of a welded final disposal canister by machining, and the fuel can be removed from the canister by using the fuel transfer machine located in the fuel handling cell. Prior to starting operation, retrieval will be tested in a joint functional test in which a canister is opened as described above and the mock-up fuel (that does not contain uranium) used in the test is removed from the canister.

If retrieval takes place after the disposal repository has been permanently closed and the encapsulation plant is no longer available, a facility to replace the decommissioned encapsulation plant will be constructed on the ground surface, if necessary, in order to process the canisters.

It is also possible to place the canisters lifted to the ground surface inside a radiation shield suitable for the canisters' road transport, for example, and transport them to the desired location for further processing.

Alternatively, the canisters can be opened and the fuel elements transferred individually to transfer casks. The transfer casks can be similar to the casks which are used for transporting fuel from the power plants to the encapsulation plant. Transfer casks can be transported by road, rail or sea.

7.1 EXPERIENCE IN CANISTER RETRIEVAL

The retrieval of a canister from conditions corresponding to final disposal has been deemed to be possible and the planned retrieval method to be feasible. A full-scale final disposal canister was successfully retrieved in the Äspö Hard Rock Laboratory, Oskarshamn in 2006. The research concerning canister retrieval progressed in four stages. First, various technologies were examined with the aim of choosing the reference technology. Attention was paid to various mechanical, hydrodynamic, heat- or cooling-based and electric methods. For reducing swelling pressure, pressurised brine was found to be the most effective method. After this, the process was developed further, and full-scale testing at the Hard Rock Laboratory started. A test provided research data on the removal of bentonite and allowed for testing canister retrieval under actual conditions. The canisters had heaters inside but no radioactive substances.

The test progressed such that, in the year 2000, two life-size copper canisters with heaters were placed in deposition holes that were lined with bentonite and located at a depth of 420 metres. The bentonite was allowed to saturate with water for 5 years. During the bentonite saturation stage, data was collected on the saturation degree, temperature, swelling pressure and movements in the bentonite blocks. Instruments were installed in the rock for the purpose of monitoring the temperature, states of strain and movements. Additionally, the deformation of the copper shell and canister temperature were measured.

The release of the canister from bentonite was started in early 2006. Initially, part of the bentonite was removed mechanically in order to take samples and remove the sensors embedded inside it. After the bentonite was removed until halfway to the canister, the rest was removed by sludging it with brine. Once the canister had been fully released from the bentonite, it was raised up, the deposition hole was flushed and the water was removed from the hole.

8 REGARDING THE COSTS OF RETRIEVAL

The assessment of retrievability costs is made difficult in particular by the fact that a possible retrieval event will taking place at an undetermined time in the future. The assessments presented below are based on the cost level at the time of submitting the construction licence application. Among other things, the development of technology will affect the magnitude of the costs, and the cost assessments must have somewhat large margins of error.

The retrieval costs are greatly dependent on the time of the retrieval, because the costs will grow gradually as backfilling of the repository is carried out. If a decision is made to retrieve a canister to the ground surface before the deposition hole is closed, the work will take approximately one day and lead to minor costs.

It is estimated that opening one backfilled deposition tunnel and retrieving the canisters contained therein to the ground surface would take approximately 500 days and cost approximately EUR 5 million. In this case, the retrieval costs would be EUR 167,000 per canister.

It is estimated that retrieving the canisters from an individual deposition tunnel would take approximately 70 months in a scenario where the disposal facility has been decommissioned. In this case, the estimated costs for opening the shaft, driving lane and central tunnel and for emptying the deposition tunnel and retrieving the canisters would be EUR 27 million.

If a decision is made to retrieve all the canisters after the repository is closed, it can be assessed that the work would cost 30 to 50% of the construction, operation and closure costs of the disposal repository.

9 SUMMARY

Safety analyses indicate that the final disposal of spent nuclear fuel is a safe solution. Therefore, retrieving the spent nuclear fuel is not necessary. However, it is possible to open the repository and retrieve the fuel canisters, should it become reasonable due to technological advancements. It is possible that, in the future, it will become desirable to use a new kind of final disposal method or completely new technology for handling spent fuel, or to utilise or reuse the raw materials or energy stored in the final disposal material. The retrieval of nuclear fuel placed in final disposal is technically feasible at the operation stage of the disposal repository and after the closure of the disposal repository.

Tests conducted in Äspö and a full-scale canister retrieval test conducted in Posiva's joint functional test demonstrate that the retrieval of a canister is possible and the method is feasible. Furthermore, it was demonstrated that it is possible to build a device for releasing the canister from swollen bentonite. If a decision is made to retrieve the canisters, sufficient time must be allocated for building and demonstrating this device before the retrieval is started.

It is challenging to assess the costs for retrieving canisters, as the costs are dependent on the time of the retrieval. The more time has passed since the final disposal and the closure of the disposal facility, the more costly the retrieval becomes. If a canister is retrieved to the ground surface before the deposition hole is closed, the costs will be minor. After the closure of the entire repository, it can be assessed that the work would cost 30% to 50% of the construction, operation and closure costs of the disposal repository.

12

UPDATED ANALYSIS OF THE RISKS RELATED TO THE TRANSPORT OF SPENT NUCLEAR FUEL

Photo: Posiva Oy

TABLE OF CONTENTS

1 INTRODUCTION

This study examines the transports of spent nuclear fuel accumulated during the operation of the Loviisa nuclear power plant to the Olkiluoto disposal facility in terms of radiation safety. The special areas of the study are the calculation of the transport container's dose rate and an evaluation of the dose effects resulting from normal transports and hypothetical traffic accident scenarios.

The study examines both coastal and inland road transport route alternatives. Furthermore, sea transports by ship from the port of Valko, Loviisa and directly from Hästholmen to Olkiluoto Harbour are examined.

The objective is to determine the radiation dose and health effects experienced by the population and personnel due to the radiation exposure resulting from fuel transports in normal transports as well as in exceptional scenarios.

As accident scenarios, the study analyses the effects of hypothetical traffic collision accidents; this involves discussing the significance of fuel failures of various degrees in terms of potential releases, spreading and the radiation doses caused.

2 SAFETY PROCEDURES FOR TRANSPORTS OF SPENT NUCLEAR FUEL

2.1 INTERNATIONAL PROCEDURES

2.1.1 PROCEDURES BY THE IAEA FOR TRANSPORTS OF IRRADIATED FUEL

The procedures by the International Atomic Energy Agency, IAEA are generally applicable to different modes of transport. The purpose of the procedures is to ensure that transports of nuclear material or nuclear waste use approved packaging in order to ensure that the radiation doses incurred by the transport personnel and population remain at the normally allowable level.

The IAEA defines the characteristics required for transport packages based on the activity and radiation properties of the substance contained in the package (IAEA, 2018). Furthermore, the package must withstand the potential loads of the transport environment in terms of its structural type and strength.

For transporting spent nuclear fuel irradiated in a reactor, a strong, cast-iron or steel transport container of type B(U)F must be used. Type B transport containers are designed to maintain sufficient environmental radiation protection and fuel protection even in severe traffic transport accident scenarios. Furthermore, the transport packaging must meet the criticality safety characteristics that are required in transports of fissile (F) nuclear fuel.

The radiation dose rate outside the transport container may not exceed the following limits (IAEA, 2018):

- 10 mSv/h anywhere on the external surface of the container; the dose rate on the surface may only exceed 2 mSv/h provided that
  - the vehicle is equipped with an enclosure that, during routine conditions of transport, prevents the access of unauthorized persons to the interior of the enclosure.
  - provisions are made to ensure that the transport container and vehicle enclosure remain fixed during routine conditions of transport.
  - the loading or unloading of fuel elements does not take place during the transport.
- 2 mSv/h at any point on the outer surface of the vehicle, including the upper and lower surfaces or, in the case of an open vehicle, at any point on the vertical planes projected from the outer edges of the vehicle.
- 0.1 mSv/h at any point 2 m from the vehicle or, in the case of an open vehicle, at any point on the vertical planes projected 2 m from the vehicle.

The container used in the road transport of spent nuclear fuel extends almost to the edges of the transport platform on top of the truck bogie and, thereby, to the edges of the vehicle. Thus, in practice, the radiation dose rate on the outer surface of the transport container should not exceed 2 mSv/h.

The radioactivity due to the surface contamination of the container may not exceed 4 Bq/cm^2 and, in terms of certain radionuclides, 0.4 Bq/cm^2.

According to the IAEA's requirements, the transport container must be able to withstand, during routine conditions of transport:[1]

- a water spray for one hour
- a drop from a height of 0.3–1.2 m onto an unyielding surface
- a compressive load equivalent to 5 times the weight of the container
- a penetration test in which a 6-kg steel bar is dropped from a height of 1 m towards the side wall of the container.

In relation to the drop test mentioned above, risk assessment must pay attention to the safety

1 Routine conditions of transport refer to conditions in which the transport container is only subjected to relatively minor stresses and the transport container maintains its tightness against a prolonged spray of liquid or rainfall. In normal conditions, the transport container must withstand a handling disturbance equivalent to a drop from a low height without impact attenuators and a high localised stress on the outer surface.

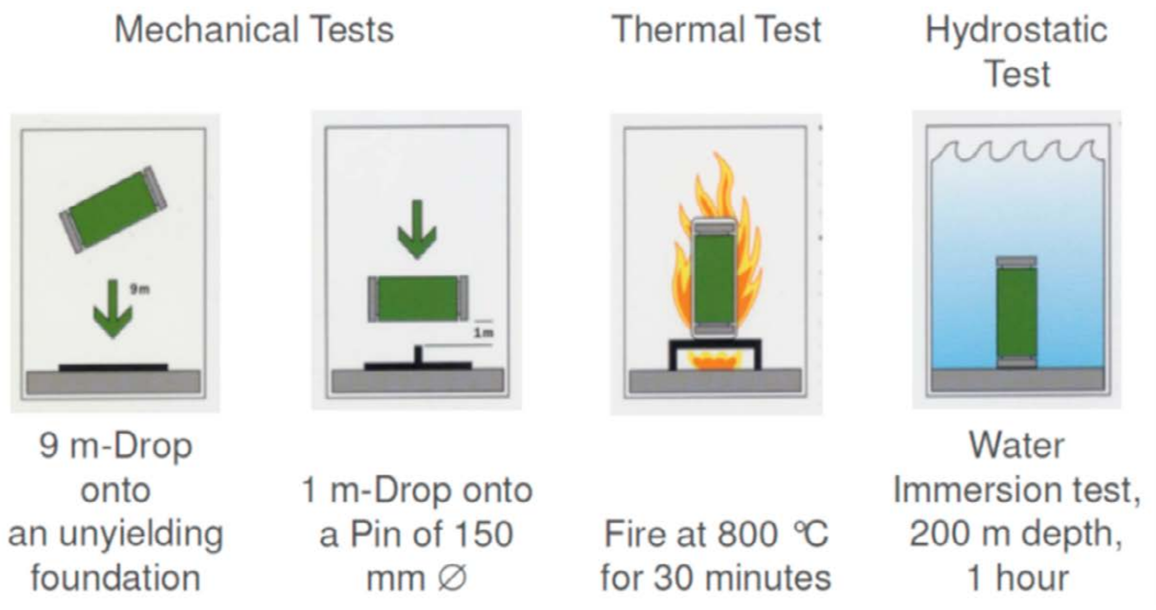


Figure 1. Accident situation tests required for the type approval and operating permit of the transport container (photo: GNS).

of lifting operations carried out without impact attenuators. In case of failed lifting, the structure of the transport container will likely remain intact, but the target being hit may suffer damage.

Transport container for spent nuclear fuel fitted with impact absorbers[2] in order to mitigate traffic accidents or exceptional loads must meet considerably stricter IAEA requirements (Figure 1); the transport container must withstand the following, among other things:

- a drop to a firm surface from a height of 9 m at an angle that results in the most unfavourable consequences
- a drop from a height of 1 m onto a steel bar with a diameter of 0.15 m
- exposure to a pool fire for at least 30 minutes with the flames fully engulfing the container and maintaining a temperature of 800°C
- immersion at a depth of 200 m for at least one hour.

The tests that are related to exceptional scenarios strive to cover the mechanical and thermal loads caused by potential accident situations, including impacts to the container caused by collisions and a fire in a vehicle transporting flammable liquids. Furthermore, it must be considered that, in reality, the target is not unyielding. In a 9-m drop test, the transport container reaches a speed of almost 50 km/h by the point of impact; this is a possible impact speed with another vehicle or obstacle even in a practical accident situation. During transportation, the spent nuclear fuel inside the transport container must remain subcritical under all conditions.

2.1.1 THE IMDG CODE FOR MARITIME TRANSPORTS OF DANGEROUS GOODS

The rules for maritime transports of goods or substances that are classified as potentially dangerous are presented in the IMDG code (International Maritime Dangerous Goods Code). The development of the code began at the Safety of Life at Sea (SOLAS) convention in 1960, which declared that different countries should adopt a harmonised international practice and code for maritime transports of goods classified as dangerous. A working group from the International Maritime Organization, IMO, began preparing the IMDG code in 1961 in close collaboration with an expert committee under the United Nations. The adoption of the IMDG code was confirmed in an IMO assembly in 1965.

The IMDG code divides dangerous substances into various classes, whose numbering does not

2 For transports on public roads, impact attenuators fitted at the ends of the transport container must be used.

directly reflect the danger index of the substance in question. The rules applicable to radioactive materials are included in Class 7. The IMDG code provides general basic principles as well as detailed recommendations relating to substances, goods and best practices in transportation, including packing, marking, storage, separation, handling and rescue operations. Compliance with the code ensures that goods transported by sea are packed in a manner that ensures safe maritime transport.

Irradiated fuel is transported on a special vessel without any other cargo. In 1993, the IMO presented design recommendations for vessels that transport irradiated fuel or high-level radioactive waste. In January 2001, these voluntary recommendations became mandatory requirements (International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Waste on Board Ships, INF Code).

Vessels are divided into three classes according to the transported activity level and their safety characteristics: INF 1, INF 2 and INF 3. Due to the high-level activity, transports of spent fuel from Loviisa require using class INF 3 vessels.

When transporting irradiated fuel, the following safety factors must be considered, among other things:

- minimising transport time
- minimising transport container transfers
- damage prevention and resistance
- fire prevention
- temperature monitoring inside the hold
- structural inspections (integrity, durability)
- security arrangements
- electricity supply
- radiation protection equipment
- leadership, training and rescue readiness.

2.2 NATIONAL PROCEDURES

2.2.1 NUCLEAR ENERGY ACT AND THE YVL GUIDE BY THE RADIATION AND NUCLEAR SAFETY AUTHORITY

Transports of nuclear material and nuclear waste constitute use of nuclear energy under the Nuclear Energy Act (990/1987). Thus, transports of spent nuclear fuel are subject to the safety principles and licences as specified in nuclear energy legislation. Section 115 of the Nuclear Energy Decree (161/1988) stipulates that the transport cannot be commenced until the Radiation and Nuclear Safety Authority (STUK) has ascertained that the transport arrangements and the arrangements for physical protection and emergency planning meet the requirements set for them. STUK presents its requirements for transports of nuclear material in Guide YVL D.2.

The transport of spent nuclear fuel requires a transport licence issued by the Radiation and Nuclear Safety Authority. In connection with the licence application, the licensee shall submit to the Radiation and Nuclear Safety Authority a transport plan and a transport safety plan for approval. Furthermore, because the radioactivity content of the spent fuel transport container exceeds 1,000 TBq, an emergency plan on the transports must also be prepared for the Radiation and Nuclear Safety Authority. The transport licence application as well as the plans for transport, safety and emergencies must be submitted to the Radiation and Nuclear Safety Authority for approval no later than three months before the planned time of transport. As an enclosure to the transport licence application, the licensee must also include an account of the arrangements of liability for nuclear damage (161/1988), Section 58.

In the transport plan, the operator must present how the transport arrangements are implemented in accordance with the requirements included in codes applicable to the transports. The transport safety plan must indicate how the safety requirements according to the YVL Guide are implemented. The emergency plan specifies the preparations for and, among other things, the measures in case of potential accident situations in which radioactive substances could be released into the environment and the radiation doses incurred by transport personnel and individuals in the general population in case of emergencies.

The consignor shall provide the consignee with the necessary information related to the transport and request the consignee's confirmation of the arrival of the transport.

The transport shall advance as quickly as possible, taking into account the limitations from the Road Traffic Act, and the number of transfers of spent nuclear fuel between vehicles and temporary storage locations must be minimised. The operator shall conduct an up-to-date risk analysis for its transport operations.

The Radiation and Nuclear Safety Authority conducts supervision and collaborates with the rescue authorities and the police, among others, in order to ensure the safety of transports.

More detailed instructions on the requirements, licence applications and content of required plans relating to transports are presented in the YVL Guides by the Radiation and Nuclear Safety Authority.

2.2.2 ACT ON THE ROAD TRANSPORT OF DANGEROUS GOODS

Government Decree 194/2002 and the regulation by the Ministry of Transport and Communications (TRAFICOM/82133/03.04.03.00/2019) on the road transport of dangerous goods set forth the provisions concerning road transports by virtue of (719/1994, Act on the Transport of Dangerous Goods). The provisions relate to packagings, containers, transport vehicles, transport units, radiation protection, route limitations and documentation.

The regulation TRAFICOM/82133/03.04.03.00/2019 is based on the IAEA's recommendations for radioactive materials, so the regulatory authority for the materials and the transport packaging in Finland is STUK. After the transport licence application has been processed, STUK may issue a transport licence that can be, in terms of the transport packaging, based on the approved safety analysis presented by a foreign operator that certifies the safety of the structural type of the transport container.

3 TRANSPORT ARRANGEMENTS

3.1 TRANSFER OF SPENT FUEL FROM THE LOVIISA NUCLEAR POWER PLANT TO THE ENCAPSULATION PLANT AT OLKILUOTO

3.1.1 PREPARATIONS AT THE PLANT

A report on the options for transporting spent fuel from Loviisa and on practical arrangements has been prepared under a separate assignment by Posiva (Capacent, 2016). Fortum's previous implementation method report has also provided detailed descriptions of the transport arrangements, vehicles and transport container options (Koskivirta, 2012).

Spent fuel that has been irradiated at the Loviisa nuclear power plant and cooled for at least 20 years after being removed from the reactor is loaded into a transport container at the spent fuel interim storage. In connection with closing the lids, the inside of the container is dried and the container is filled with helium under negative pressure. After this, at the loading station of the interim storage, the container is lowered into a horizontal position either onto a separate platform or a low-bed trailer and locked in place in the transport cradle. Impact attenuators are installed at the ends of the transport container for the duration of the transport.

Due to the high weight of the loaded transport container (116 t), the capacity of the loading station crane must be at least some 125 t. It must be possible to drive a truck and low-bed trailer combination of approximately 30 m in length completely inside the loading corridor of the loading station in order to conduct the loading safely and according to the regulations. According to the safety regulations, the loading hatch on the ceiling of the loading space and the doors of the loading space must not be open at the same time.

3.1.2 TRANSPORT OPTIONS

Figure 2. Partial photograph of the area outside the Loviisa nuclear power plant's spent fuel loading station (Photo: Capacent).

From the plant, the fuel is transported primarily by road or by sea to the encapsulation plant and disposal facility at Olkiluoto. In the road transport option, the transport container is taken directly to Olkiluoto using a suitable route. In the sea transport option, the transport container is taken either directly from the Loviisa plant to the port located in the Olkiluoto power plant area or from the port of Valko, Loviisa to Olkiluoto on board a specially equipped ship. Sea transports departing from the Loviisa plant site would require building a port with sufficient depth adjacent to the Loviisa nuclear power plant in Hästholmen. In this case, the transport containers could be moved from the plant into the ship's hold using trestle platforms. The transport container would be transported from the plant to the Valko Port along Saaristotie road and through the centre of Loviisa. Valko Port allows for using ro-ro type (Roll-on/roll-off) loading to the ship's hold, i.e. a method where the transport container is moved into the hold using a vehicle. The implementation method for ro-ro loading is presented in Figure 3.

From the Olkiluoto reception port, the transport containers can be moved on trestle platforms from the port to the encapsulation plant's reception facility.

■ **Figure 3.** Loading/unloading of a transport container transported inside a ship's hold.

Sea transport allows for transporting several containers of spent nuclear fuel at the same time by ship from Loviisa to Olkiluoto.

3.1.3 RETURNING EMPTY TRANSPORT CONTAINERS

When transport containers are returned from the Olkiluoto encapsulation plant to the Loviisa nuclear power plant, there may be radioactive particles on the inside surfaces of the container and cover part (dry transport). According to the initial plans, the inside surfaces of a contaminated container would be cleaned at the Loviisa nuclear power plant by using a separate decontamination system (Koskivirta, 2012).

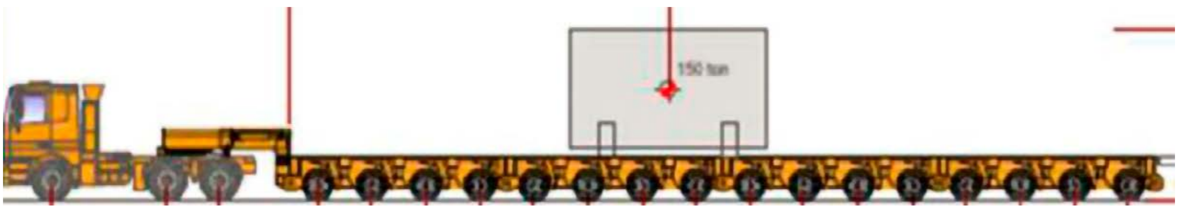
The internal contamination of a transport container does not cause a significant radiation exposure to the population outside of the thick steel walls of the container that attenuate radiation effectively.

Before the return shipment leaves Olkiluoto, the possible contamination level outside the container must also be measured. If necessary, the outside surfaces of the transport container must be cleaned of any radioactive particles before the transport container is returned. The return transport is carried out according to the transportation codes.

3.2 DESCRIPTION OF THE TRANSPORT EQUIPMENT

3.2.1 ROAD TRANSPORT

Because of the height of the transport container and the stability of the transport, heavy containers that contain fuel are usually transported by road with the long side of the container in a horizontal position (Figure 4). A container that leaves the Loviisa plant for Olkiluoto can be transported in a horizontal position with the maximum load



■ **Figure 4.** A transport vehicle type suitable for Loviisa's fuel transports (Posiva).

Figure 5. The specially equipped m/s Sigrid (SKB) that is suitable for fuel transports.

height of 4.4 m measured from the ground level, which is the maximum height for special transports specified in the legislation. This takes into account the safety allowance concerning the actual heights of underpasses measured from the ground level.

The transport vehicle is a combination of a truck and a low-bed trailer. The decree by the Ministry of Transport and Communications (1253/2002) concerning the Vehicles Act sets restrictions for the masses focused on axles, i.e. axle weights, and transport speeds: "For a special transport trailer, the maximum allowable mass focused on an axle fitted with dual tyres or installed in a bogie at a speed of 80 km/h is 13 tonnes and, respectively, 20 tonnes on an axle fitted with eight parallel tyres." Depending on the tyre arrangement of the low-bed trailer section, the axle weights must remain within the allowed range, taking into account the total weight of the loaded CASTOR container and its transport protection. The decree specifies that the transport width must not exceed 3.2 m.

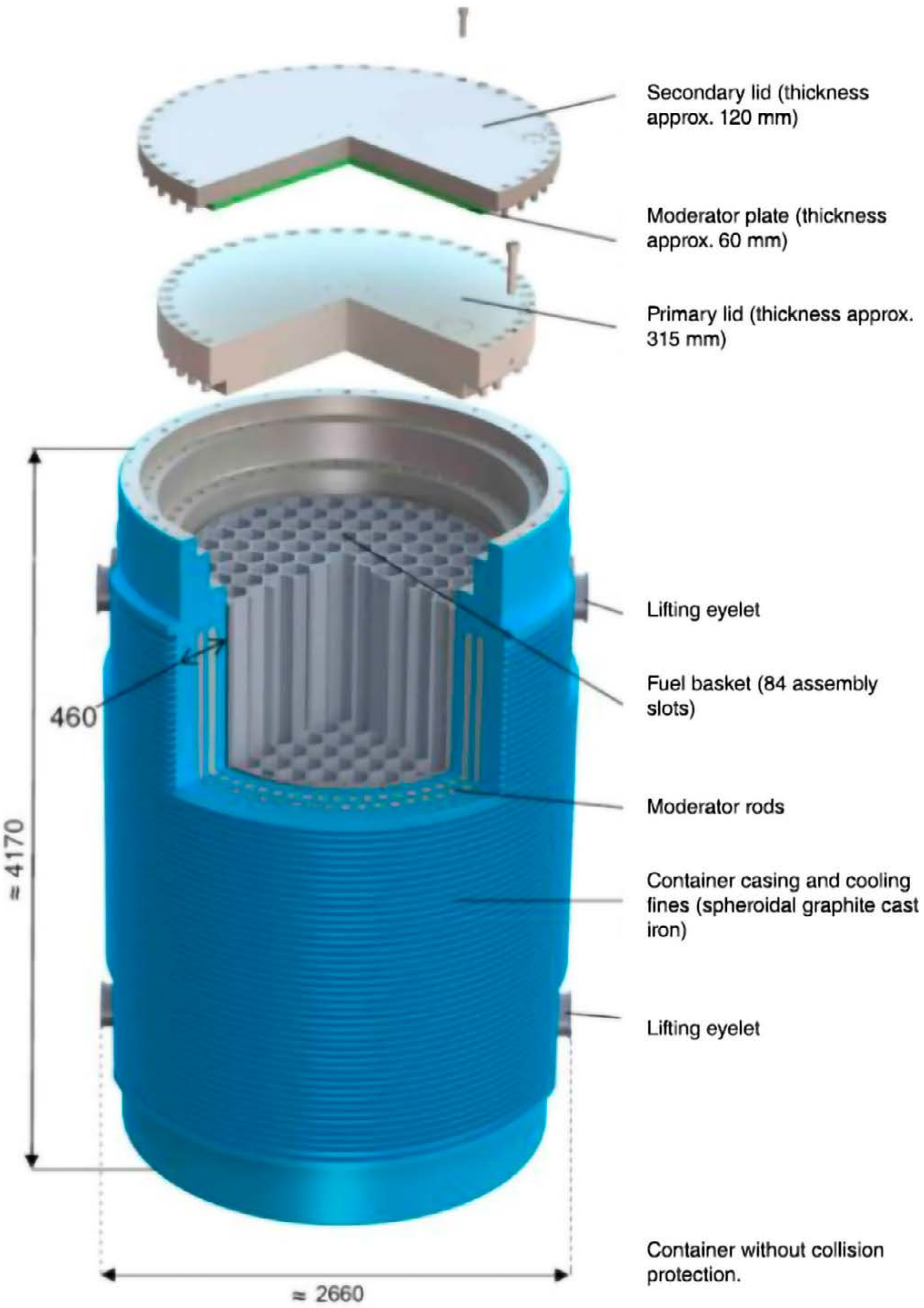
During the transport, the transport container must be secured and locked onto the transport platform. For this purpose, there is a so-called transport cradle available and designed for the CASTOR VVER 84 container, which allows for reliably placing, securing and locking the container onto the platform.

3.2.2 SEA TRANSPORT

The transports of irradiated fuel use special ships that feature solutions for ensuring the safety of sea transport, including a double-bottom structure for preventing sinking in case of potentially running aground. Furthermore, the ship must be fitted with, for example, cargo space temperature monitoring and management equipment, advanced and redundant communication equipment and other specific features for improving safety.

The transports of power reactor fuel, such as the transports from the spent fuel interim storage in Loviisa, require a ship compliant with the highest safety class (INF 3) according to the International Maritime Organization's (IMO) guidelines due to the fuel transport containers' high activity content. On the other hand, Class INF 3 does not specify limitations for the total activity of a single transport.

Russia, the United Kingdom and Sweden, for example, can offer transport services and ships that are suitable for the transport of spent nuclear fuel in the European region. The Swedish m/s Sigyn was used for a long time for transports in the Baltic Sea, and SKB's currently operating m/s Sigrid, which was completed in 2013, can be considered to be even more advanced in terms of its level of safety (Figure 5). Its provided design specification is as follows: length 99.5 m, width 18.6 m, dead weight 1,600 t, draught approx. 4.5 m and travel speed 12 knots. It has a loading capacity of 12 transport containers at once.



Number of loaded VVER assemblies	84 pcs
Maximum fuel burn-up	58 MWd/kgU
Thermal power inside the container	< 27.5 kW
Height	4.17 m
Diameter	2.66 m
Wall thickness	0.46 m
Weight: empty/with full fuel load	106 t/116 t

Figure 6. CASTOR® 440/84M transport container (GNS, 2017).

3.3 TRANSPORT CONTAINER

The transport container must meet the international safety requirements for transports of highly radioactive spent nuclear fuel in compliance with the IAEA guidelines. The container must pass the tests that replicate normal transports and exceptional accident situations (drop onto a hard surface, drop onto a bar, fire, immersion in deep water). The radiation dose rate must remain at an allowable level outside the transport container.

In terms of container types, there are many alternatives depending on e.g. whether the transport is completed with gas cooling or water cooling. In a gas-cooled container, the filler gas can be helium under negative pressure. The current plan is to use a gas-cooled transport container for transporting spent fuel from Loviisa. This will facilitate the processing of the container during the loading and unloading stages at the Loviisa nuclear power plant and the Olkiluoto encapsulation plant. When using a container filled with water, the large quantity of water would have to be replaced and the container decontaminated.

The CASTOR transport containers are internationally in widespread use for fuel transports. They are compatible with the IAEA's B(U)F container requirements and have undergone a foreign permit process and authority approval, whose validity in Finland can be applied for from the Radiation and Nuclear Safety Authority.

The VVER fuel assemblies from the Loviisa plant are suited for e.g. the CASTOR 440/84M type transport container (Figure 6 with the technical specifications of the container). The body of the container is made of spheroidal graphite cast iron, and there are polyethylene rods placed inside the container shell to attenuate neutron radiation. There is a monitored space between the container covers in order to identify cover seal leaks. The interim cover plate features a polyethylene sheet for attenuating neutron radiation through the end of the container into the environment.

The fuel loaded inside the transport container has cooled for at least 20 years according to Posiva's design bases, but it will still generate some residual heat. The manufacturer-specified maximum fuel burn-up for a CASTOR 440/84M container is 58 MWd/kgU, with the maximum thermal power developing inside the container being 27.5 kW (GNS, 2017).

3.4 FUEL TYPE AND PROPERTIES

3.4.1 FUEL ELEMENT

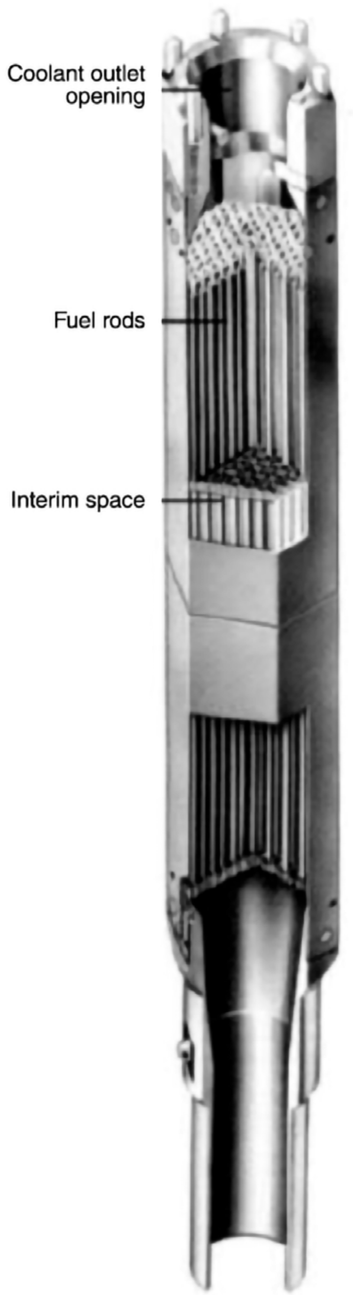


Figure 7. VVER fuel element.

	VVER 440 PWR
Cross sectional geometry of the element	Hexagonal
Element length (mm)	3217
Cross sectional width of the element (mm)	144
Number of fuel rods	126
Uranium weight inside element (kg)	120–126
Total element weight (kg)	210–214
Flow channel width (mm)	144 (hexagonal)
Estimated average burn-up of all transported fuel (MWd/kgU)	40–41
Typical U-235 degree of enrichment (%)	3.6–4.4

Table 1. Design data for the VVER fuel element.

The Loviisa nuclear power plant uses encased VVER fuel elements i.e. fuel assemblies compatible with a hexagonal grating (Figure 7). Similarly, the fuel basket inside the transport container comprises hexagonal fuel positions whose shape and length are equivalent to the fuel elements' geometry. The technical design information of VVER fuel elements is presented in Table 1.

3.4.2 BURN-UP

It is estimated that the average burn-up of the VVER fuel transported from Loviisa is approximately 40 MWd/kgU (Huttunen, et al. 2021). This burn-up estimate takes into account the increase in allowed maximum burn-up at the Loviisa plant units to 57 MWd/kgU. Figure 8. presents the development of burn-up in the

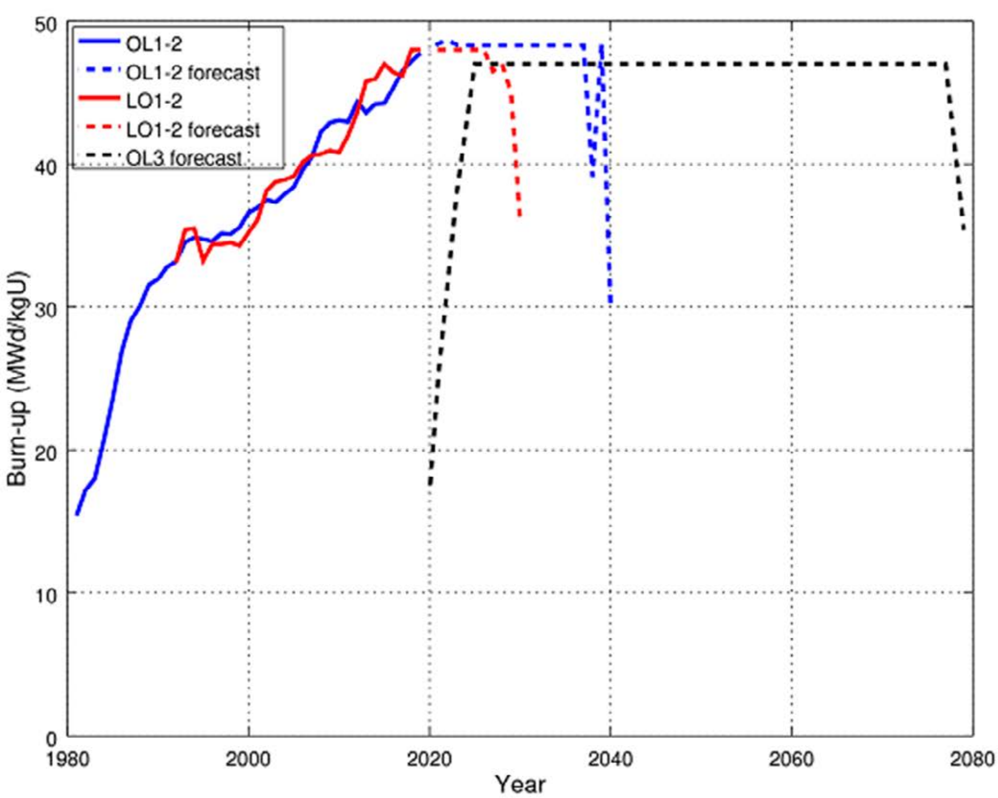


Figure 8. The development of the average burn-up of removed fuel assemblies (MWd/kgU) at the Loviisa and Olkiluoto plant units (Huttunen, et al. 2021).

removed fuel assemblies (the fuel in elements) over time at the Loviisa and Olkiluoto plant units.

3.4.3 AMOUNT OF FUEL TO BE TRANSPORTED

Over the course of 50 years of operation, the Loviisa nuclear power plant will accumulate approximately 8,000 fuel assemblies. Raising the maximum burn-up to 57 MWd/kgU reduces the accumulation rate and total number of used assemblies over the plant's planned operating life. As one transport container has capacity for 84 assemblies, nearly 100 transport containers are required. According to the current plan, the amount of fuel according to the current operating life of the Loviisa plant would be placed in final disposal within 11 years, so the calculated transport need is approximately 9 containers per year. The uranium content of one container is approximately 10 tU (84 VVER fuel assemblies).

3.5 SCHEDULE FACTORS

On terms of risk management, fuel transports should be carried out in a manner that minimises the risks related to traffic and potential social disturbances as well as the risks caused by radiation.

The need to transport spent fuel is linked to the schedule of transport reception, i.e. encapsulation and final disposal. The practical transport need for Loviisa fuel can be, for example, three transports by ship per year (3 containers per transport) or nine road transports per year (1 container per transport). Therefore, the transport need depends on the selected mode of transport and the number of transport containers procured.

During the early years of the final disposal period of approximately 40 years, the plan is to encapsulate fuel from OL1-2 at approximately 35 canisters per year, then fuel from LO1-2 at approximately 55 canisters per year and then fuel from OL1-2 ta approximately 55 canisters per year.

Low traffic flow periods provide certain advantages particularly for road transports. This way, the transports can be completed under supervision at the planned route speed and without additional delays, which is required in the procedures for transporting radioactive materials. In terms of scheduling, sea transports are more flexible than road transports, but the weather conditions must be suitable for safe sea transports.

The transport time should always be selected such that the rescue services can respond as quickly and effectively as possible in case of potential disturbances or accidents.

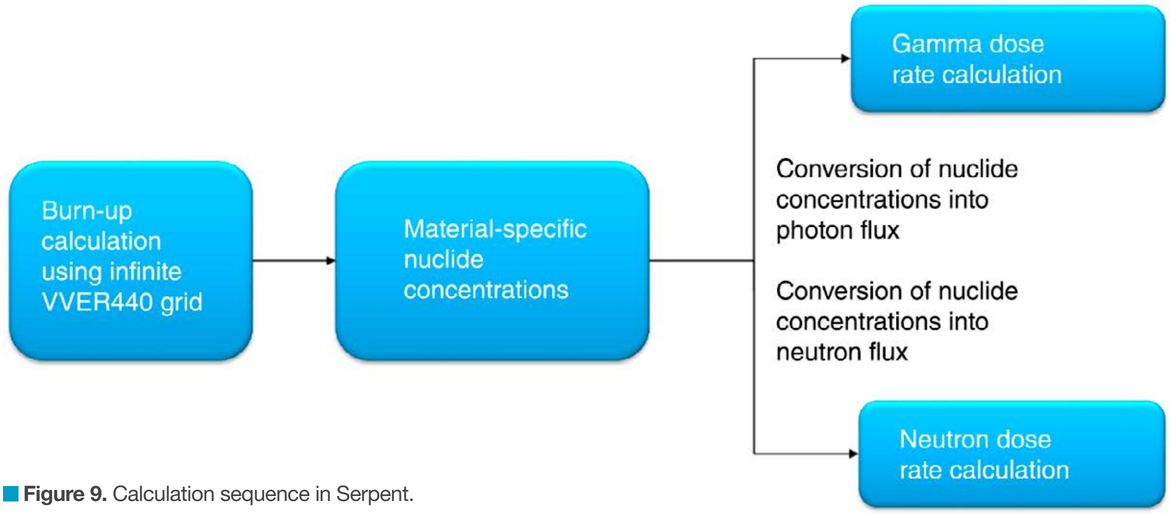
4 RADIATION DOSES

4.1 DOSE RATE OF THE TRANSPORT CONTAINER

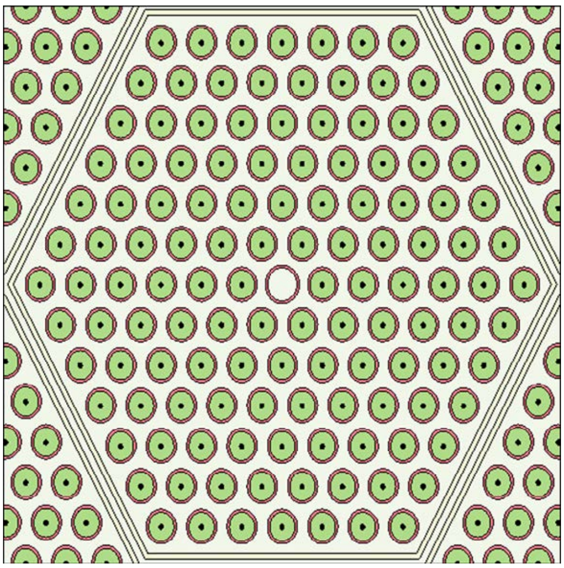
4.1.1 INITIAL DATA

The calculations were made using VTT's own Serpent software (based on Monte Carlo), version 2.1.32 (Leppänen et al., 2015). The calculation model has two parts: Initially, the composition of spent fuel was calculated with a burn-up calculation and the nuclide concentrations of the materials were saved into a binary file. Then, a model of a CASTOR container filled with fuel was created, and the calculated fuel nuclide concentrations were entered into the model. The material-specific nuclide concentrations were converted to photon and neutron fluxes in two different calculations, and the absorbed dose was calculated by using dose conversion coefficients. The calculation sequence is depicted in Figure 9.

The burn-up calculations were repeated twice, such that one of the calculations would describe a conservative extreme in terms of burn-up and degree of enrichment and the other would describe a more realistic 2nd generation TVEL fuel.



■ **Figure 9.** Calculation sequence in Serpent.



■ **Figure 10.** Modelling geometry for the burn-up calculation. An infinite grid of VVER assemblies modelled with repeating limit conditions.

Parameter	Conservative burn-up model	Realistic burn-up model
Assembly type	Hexagonal 15x15	Hexagonal 15x15
Uranium pellet diameter (cm)	0.756	0.756
Inner diameter of protective cladding (cm)	0.776	0.776
Outer diameter of protective cladding (cm)	0.915	0.915
Assembly thickness (pitch) (cm)	14.7	14.7
Distance between rods in assembly (pitch) (cm)	1.23	1.23
Degree of uranium enrichment (w%/HM)	5.0	4.4
Fuel temperature (K)	1094	1094
Cooling water temperature (K)	582	582
Water boron concentration (ppm)	500	500
Power density during burn-up (W/g)	48	48
Burn-up at the end (MWd/kgU)	60	50
Cooling time after burn-up (a)	20	20

Table 2. Some parameters for the burn-up calculation.

The burn-up calculation used the modelling of an infinite grid of VVER-440 assemblies, which were used until the initially specified burn-up (50 MWd/kgU or 60 MWd/kgU) and then cooled for 20 years. The calculation parameters are compiled in Table 2, and the modelled geometry is presented in Figure 10. The calculation used the ENDF/B-7 library and simulated 1E9 neutrons. Using VTT's own 2.60 GHz Intel Xeon cluster and 10 cores, the calculation took approximately 4 hours to complete.

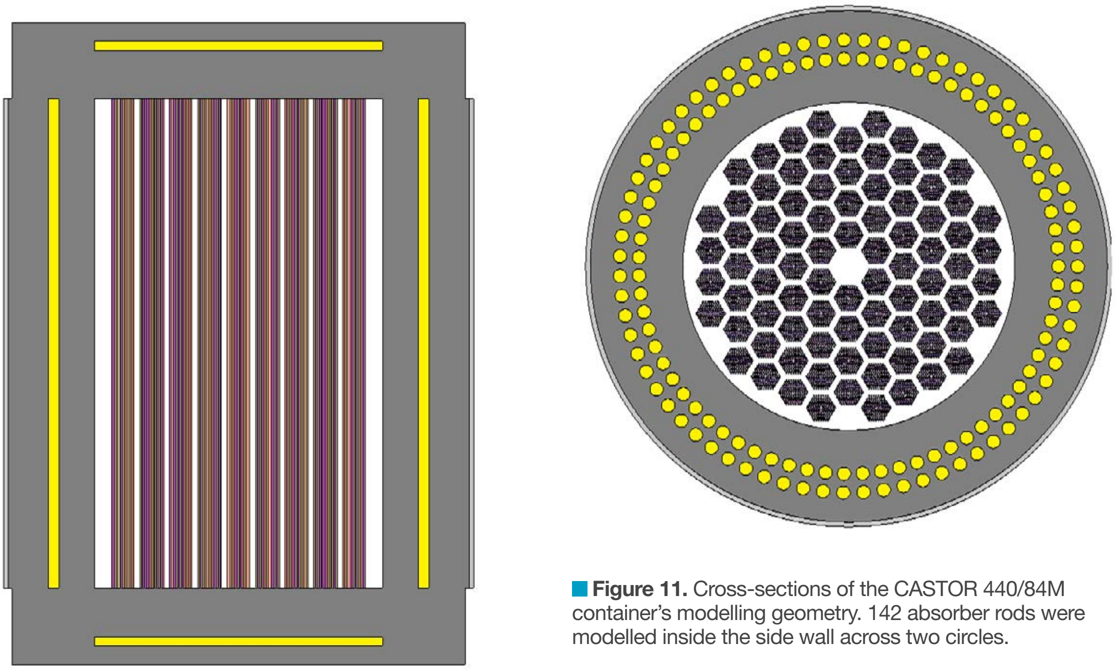
For dose rate calculation, the container was modelled in an air volume of 300x300x500. Inside the container, 84 VVER-440 assemblies were modelled, whose geometry matched that of the burn-up calculation. All 84 assemblies were assumed to be identical.

The CASTOR 440/84M container was modelled mainly according to the reference (GNS, 2014). The calculation included the modelling of the outer walls, covers and neutron absorbers inside walls and covers. Assumptions were made concerning the structural materials of the container according to the reference (PNNL, 2011).

For simplification, the calculation modelled the cooling ribs outside the container as a cylinder around the container, whose density was assumed to be the half of the density of spheroidal graphite cast iron. Furthermore, the container's lifting eyelets and the fuel assemblies' top and bottom end structures were not modelled. Inside the container, it was assumed that there was only air between the assemblies according to the reference (Kärkkäinen & Karvonen, 2018). All

Parameter	Size	Material
Container's outer radius (mm)	1330	Carbon steel, PNNL #162
Container's inner radius (mm)	870	Dry air
Inner cover thickness (mm)	315	Carbon steel, PNNL #162
Cover absorber disc thickness (mm)	60	Borated polyethylene, PNNL #247
Outer cover thickness (mm)	120	Carbon steel, PNNL #162
Side wall absorber rod diameter (mm)	70	Borated polyethylene, PNNL #247
Height of the container's inner section (mm)	3180	Dry air
Total height of the container (mm)	4170	Carbon steel, PNNL #162

Table 3. Some parameters for the dose rate calculation.



■ **Figure 11.** Cross-sections of the CASTOR 440/84M container's modelling geometry. 142 absorber rods were modelled inside the side wall across two circles.

the applied assumptions are conservative. The modelling dimensions are compiled in Table 3, and the geometry cross-section is presented in Figure 11.

Both calculations specified 20 pcs of 80x80x4 cm detectors on the side of the container 10 cm apart at various distances. All the detectors were vertically aligned with the middle of the container.

Due to a very low photon flux outside the container, the calculations used a global variance reduction by dividing the container cylinder-symmetrically into 100 radial weight windows, 50 weight windows in the direction of the plane angle and 5 vertical weight windows determined from the centre of the container.

4.1.2 DOSE RATES OUTSIDE THE CONTAINER

The calculated photon fluxes were converted to a dose rate with the NIST conversion factors built into the software (Hubbell & Seltzer, 2004), and the neutron fluxes were converted to a dose rate with the separately input ANSI-compliant energy conversion factors (ANSI, 1977).

The calculations were separately repeated for the photon and neutron doses with both burn-up values by modelling 1E12 particles in each calculation. Using VTT's own 2.60 GHz Intel Xeon cluster and 10 cores, each calculation took approximately 5 hours to complete.

Figure 12 presents the calculated photon dose rates and Figure 13 presents the calculated neutron dose rates as a function of distance measured from the container surface. Furthermore, Figure 14 presents the qualitative shape of the dose rate fields, viewed from the side of the container. Finally, figure 15 presents the combined dose rates as a function of distance measured from the container surface. The statistical uncertainty was approximately 6% for the photon dose rate calculations and approximately 1% for the neutron dose rate calculations.

Compared to the results in the reference (Kärkkäinen & Karvonen, 2018), both the photon and neutron dose rates outside the container were on a similar level, slightly under 1 µSv/h and 100 µSv/h. Due to the higher dose rate conversion factors, the dose rate caused by neutrons is approximately two decades higher. According to IAEA's SSR-6 transport regulations (IAEA, 2018 & 2012), dose rate must be limited to under 100 µSv/h at distances of under 2 m. The combined dose rates presented in Figure 15 are below this limit.

VTT has previously conducted parameter analysis on how fuel types' burn-up and cooling time affect the characteristics of spent fuel. Neutron emission from spent fuel is particularly the result of spontaneous fission in the fuel (e.g. Pu-238). This, in turn, is significantly dependent on the fuel burn-up and cooling time. For comparison, Figure 16 presents numbers of spontaneous fission events in spent fuel at various burn-up levels and cooling times, calculated with the Serpent software. (Juutilainen & Häkkinen, 2019)

The calculations used conservative assumptions in terms of both the average fuel burn-up and the structure of the container. In reality, burn-up varies between assemblies, and dose rate can be minimised by packing assemblies with a low

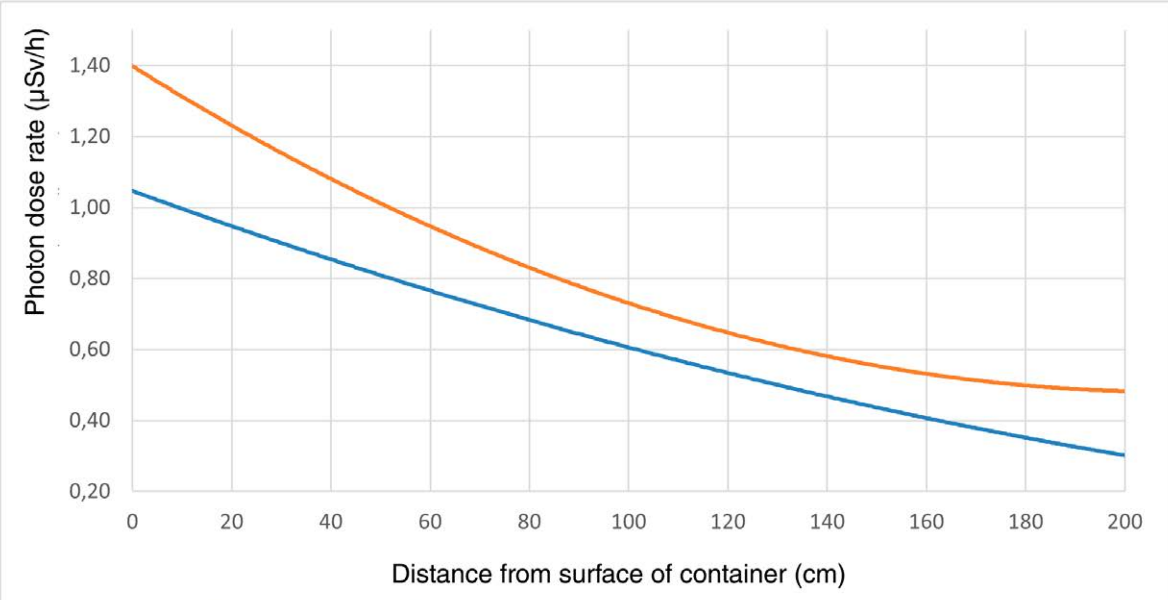


Figure 12. The calculated photon dose rates (µSv/h) as a function of distance from the container surface. The dose rate at an average burn-up of 60 MWd/kgU is presented in orange, and the dose rate at an average burn-up of 50 MWd/kgU is presented in blue. In both cases, the cooling time is assumed to be 20 years.

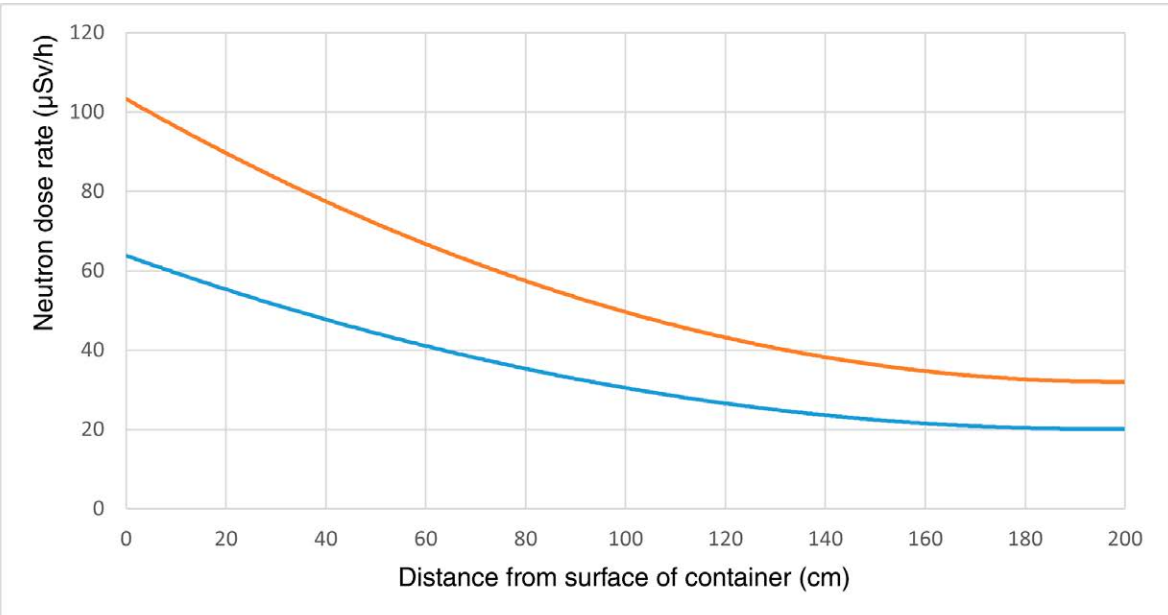
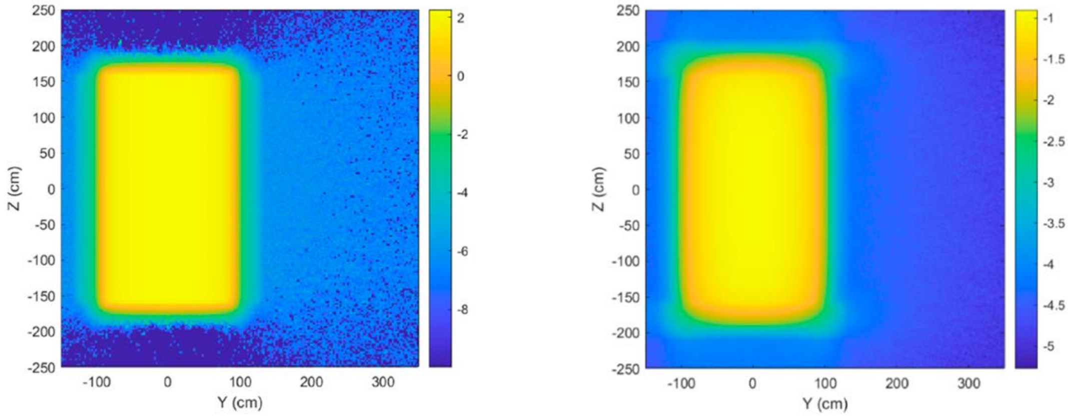
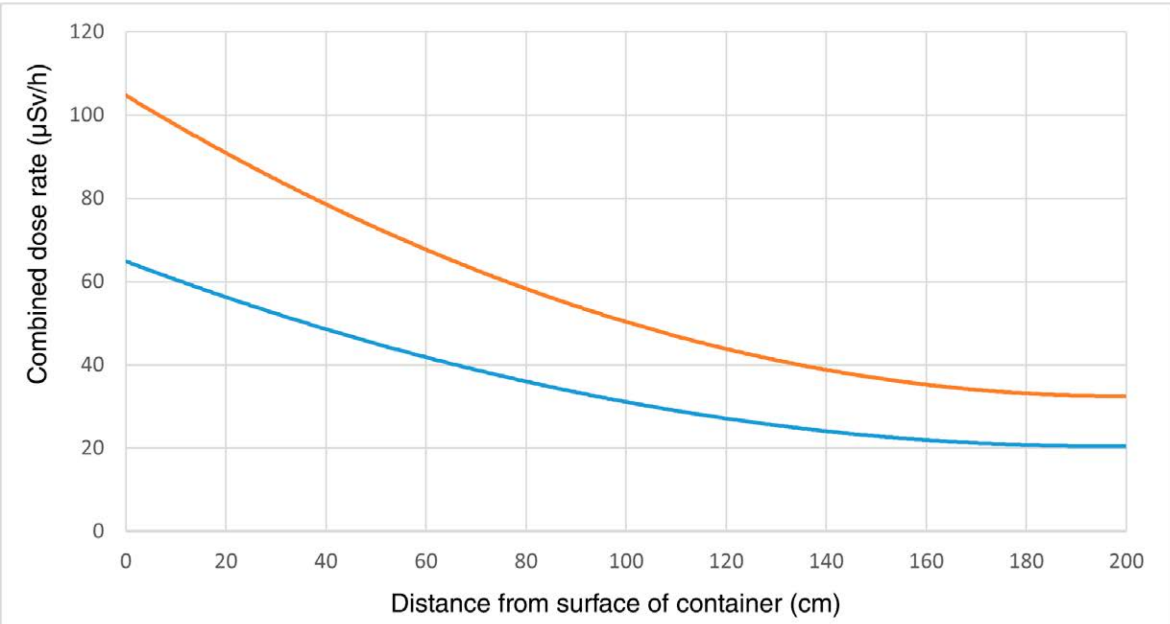


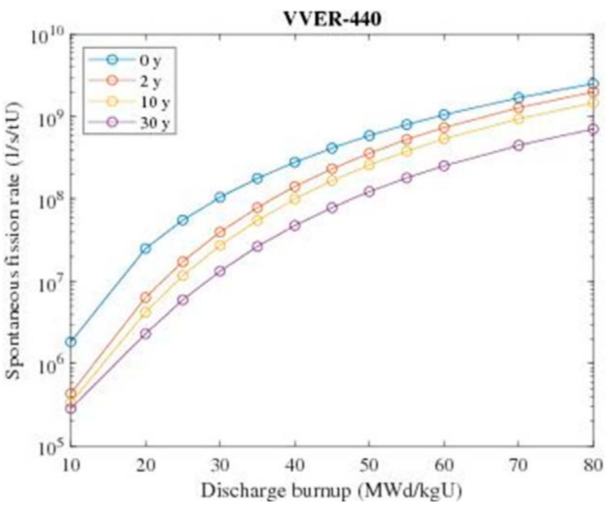
Figure 13. The calculated neutron dose rates (µSv/h) as a function of distance from the container surface. The dose rate at an average burn-up of 60 MWd/kgU is presented in orange, and the dose rate at an average burn-up of 50 MWd/kgU is presented in blue. In both cases, the cooling time is assumed to be 20 years.



■ **Figure 14.** Calculated dose rates for photons (on the left) and neutrons (on the right) around the container at an average burn-up of 50 MWd/kgU and a cooling time of 20 years. The results are presented in decades on a Sv/h scale.



■ **Figure 15.** The combined dose rates (photons + neutrons, µSv/h) as a function of distance from the container surface. The dose rate at an average burn-up of 60 MWd/kgU is presented in orange, and the dose rate at an average burn-up of 50 MWd/kgU is presented in blue. In both cases, the cooling time is assumed to be 20 years.



■ **Kuva 16.** VTT's previous calculations of the numbers of spontaneous fission events in spent fuel at various burn-up levels and cooling times.

burn-up and a long cooling time at the outside edge of the container. Furthermore, the structures between assemblies, which were excluded from the calculation, slightly reduce dose rates.

4.2 NORMAL TRANSPORTS

4.2.1 TRANSPORT ROUTES AND INITIAL DATA

The possible modes of transport for transporting spent nuclear fuel from the Loviisa nuclear power plant to the encapsulation plant and disposal facility at Olkiluoto are road transports (Figure 17) or sea transports (Figure 19). Ship transports include vehicle transports or short transfers that take place in Loviisa and Olkiluoto.

For **road transports**, the two most significant different types of route options would be a coastal route and an inland route (see Figure 17). In both road transport options, the transport departs from the Loviisa plant toward the Loviisa city centre.

On the coastal route option, the transport joins a motorway (E18) from the Loviisa centre and bypasses the Porvoo urban area. Near the capital region, the route turns to Ring III, which helps to avoid the densely populated areas of Vantaa, Helsinki and Espoo in normal transports. Then, the transport continues along the Turku motorway, which includes several tunnel sections (Figure 18). The rest of the transport takes place along national road 8 on the west coast, which has a connection to the Olkiluoto encapsulation plant after Rauma. The total length of the route is approximately 380 km.

Figure 18. A tunnel on the motorway between Helsinki and Turku.

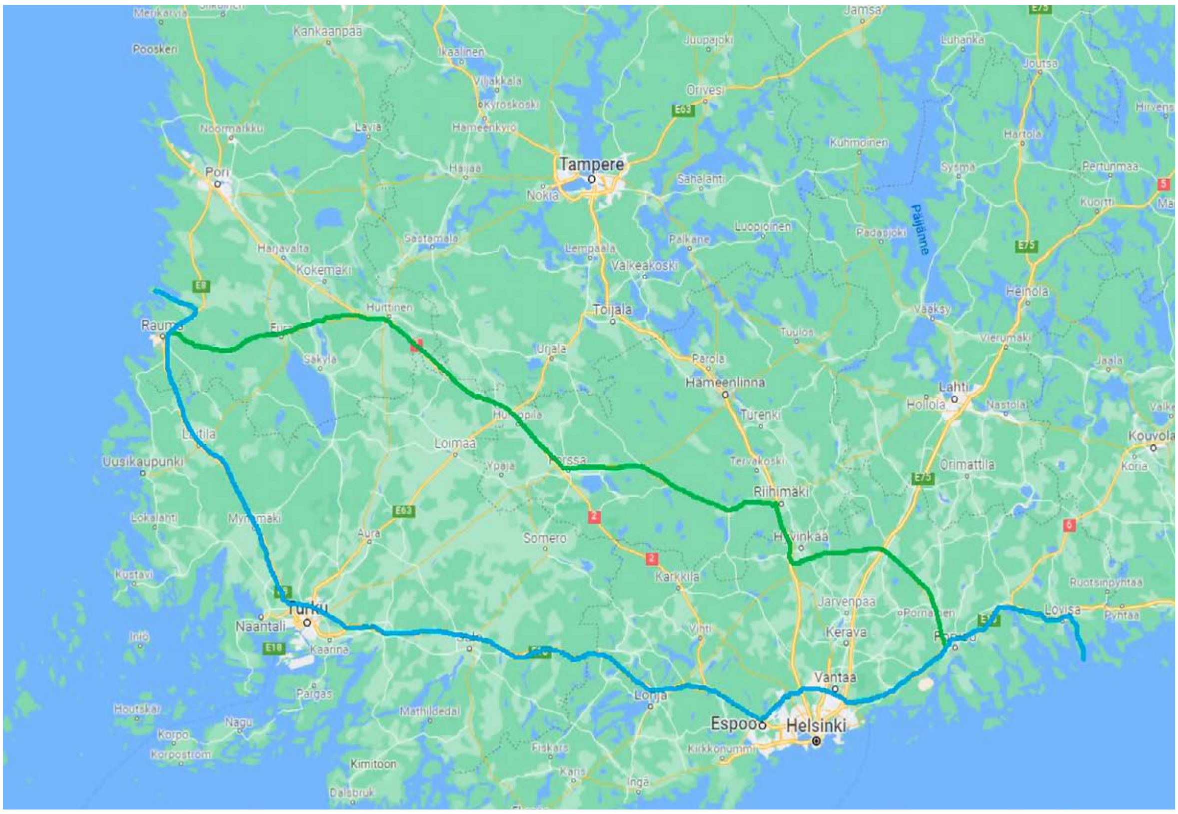


Figure 17. Road transport route options (Capacent 2016).

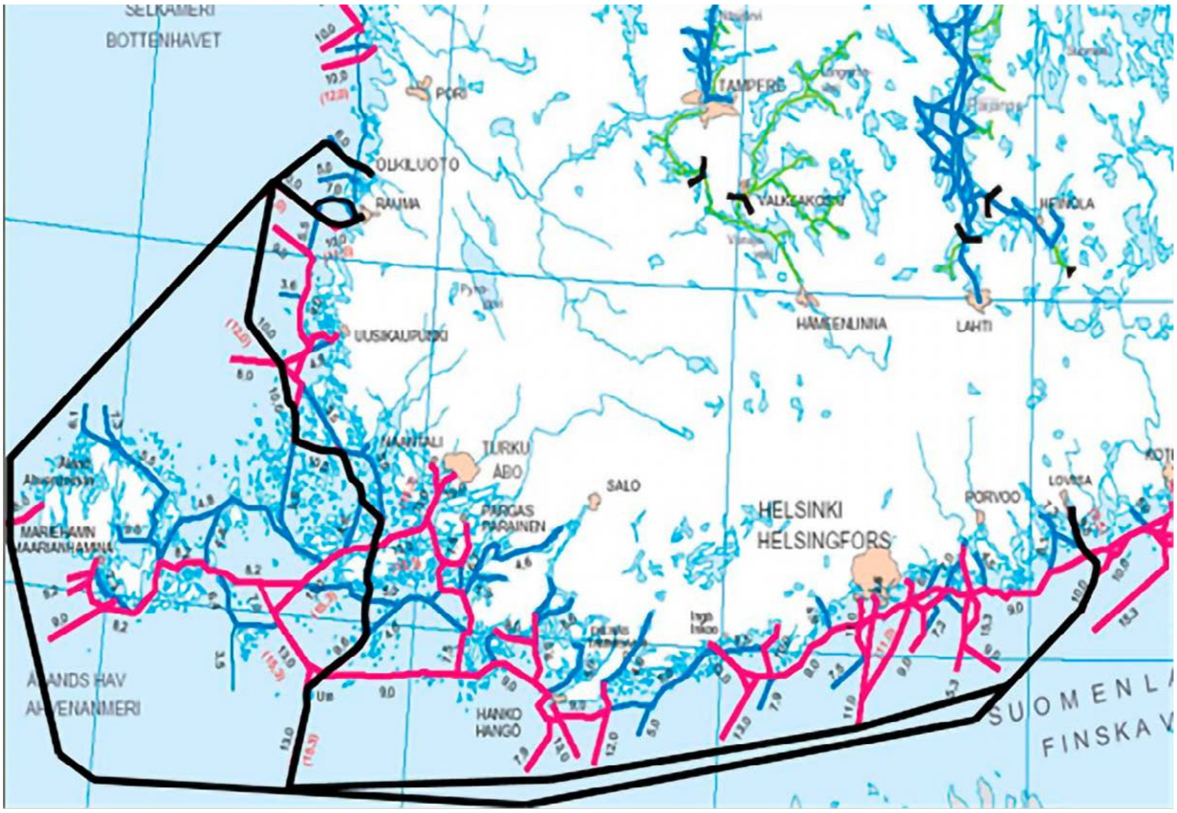
On the inland route option, the transport joins the E18 from the centre of Loviisa and continues via Hyvinkää and Forssa to Olkiluoto in Eurajoki. The total length of the route is approximately 350 km. The inland route avoids population. The inland route is shorter than the coastal route, but the coastal route allows for a higher effective speed, which has favourable effects in terms of the radiation exposure of the transport personnel, as is demonstrated by the results hereinafter.

Both the coastal route and the inland route can be considered to provide their own advantages and disadvantages. The inland route has a lower density of other traffic. The inland route is primarily a two-way road where the fuel transport would meet traffic coming in the opposite direction. Furthermore, the route is more meandering and has more hills than the coastal route. Particularly with heavy transports, there is little time to react to surprising disturbances. If the transport stops due to a technical fault or another reason, it will be difficult to route traffic round the transport vehicle on a narrow two-way road, and this can result in hazardous situations.

The coastal route has a higher density of traffic compared to the inland route. For a large portion of the way, the transport road is a wide motorway with two lanes going in each direction. Furthermore, there are wide protective areas with embankments on the sides of the motorway. The route does not meander much, and the transport would advance along a clear road profile. The intersection areas are mostly ramps which are easier for a large vehicle than tight T intersections. Should the transport have to stop, traffic could be routed around the vehicle due to sufficient road width and the two lanes going in the same direction.

In addition to road safety, the evaluation of road and sea routes involves other factors that have been discussed separately.

In the sea transport option, the first part of the transportation would take place in the national or international sea area of the Gulf of Finland (Figure 19). The rest of the ship route would pass via the Archipelago Sea or Sea of Åland directly to Olkiluoto Port, from where the cargo would be taken by road to the Olkiluoto encapsulation plant. According to the current situation, the fuel containers would be first transported by road from Hästholmen to the port of Valko, Loviisa and then taken by ship to Olkiluoto. One option



■ **Figure 19.** Ship route alternatives in black, via the Archipelago Sea or Sea of Åland.

would be to start the sea transport already in Hästholmen, but this would require building a port with sufficient depth adjacent to the Loviisa nuclear power plant in Hästholmen.

The detailed initial data for calculations in terms of the transport routes are presented in Tables 4 and 5. The intensity of radiation and radiation exposure decreases as distance from the transport container grows. This way, in normal transports, the effective scope of radiation practically covers the near surroundings of the transport route; some tens of meters from the storage container. The passengers of vehicles passed during the transport are more exposed to radiation than the population farther away. The initial data in the table is presented homogenised in sequences, and it describes the situation along the transport route and in its near surroundings. Thus, the wide protective areas along motorways or the Ring III, which is similar to a motorway, affect the chosen initial data, such as the density of the effectively exposed population.

Route 1 (TR1)	**Hästholmen-Määrlahti-Porvoo-Vantaa(Ring III)-Espoo-Paimio**				
("Coastal route")	(sections 1–5)				
Initial data	LO-Määr	Määr-Por	Por-Van	Van-Esp	Esp-Pai
	road	road	road	road	road
Length (km) in total 381	14	31	34	36	130
Traffic density in total (vehicles/h)	30	125	250	460	400
Accident frequency (1/km)	1.00-E07	1.00-E08	1.00-E08	5.00-E08	1.00-E08
Population density (persons/km2)	15	7	7	45	8
Transports per year	9	9	9	9	9
Containers per transport	1	1	1	1	1
Dose rate at 1 m (mSv/h)	0,05	0,05	0,05	0,05	0,05
Transport speed (km/h)	35	60	60	55	60
Number of transport personnel	2	2	2	2	2
Average distance between container and transport personnel (m)	10	10	10	10	10
Handling of containers (per transport)	1	0	0	0	0
Duration of stops (h/km)	0,005	0,005	0,005	0,01	0,005
Number of persons exposed to radiation during stops	10	10	10	30	10
Distance between container and exposed persons during stops (m)	10	10	10	10	10
Storage time (h/transport)	0	0	0	0	0
Number of persons exposed to radiation during storage	0	0	0	0	0
Distance between container and exposed persons during storage (m)	0	0	0	0	0
Convoy (persons)	8	8	8	8	8
Share of urban area transport during rush hour				0	
Share of urban area transport in the centre				0,2	
Share of transport on motorway	0	1	1	1	1
further information: Container CASTOR-VVER 440/84M (maximum loaded weight 140 t)					

Table 4. Initial data for the coastal transport route, sections 1–5

Route 1 (TR1)	**Paimio-Raisio-Masku-Mynämäki**				
("Coastal route")	(sections 6–10)				
Initial data	Pai-Rai	Rai-Mas	Mas(TA)	Mas-Myn	Myn(TA)
	road	road	road	road	road
Length (km) in total 381	29	8	3	11	4
Traffic density in total (vehicles/h)	570	450	590	310	340
Accident frequency (1/km)	1.00-E08	5.00-E07	5.00-E07	1.00-E07	5.00-E07
Population density (persons/km2)	15	20	55	15	30
Transports per year	9	9	9	9	9
Containers per transport	1	1	1	1	1
Dose rate at 1 m (mSv/h)	0,05	0,05	0,05	0,05	0,05
Transport speed (km/h)	60	60	40	60	40
Number of transport personnel	2	2	2	2	2
Average distance between container and transport personnel (m)	10	10	10	10	10
Handling of containers (per transport)	0	0	0	0	0
Duration of stops (h/km)	0,005	0,005	0,01	0,005	0,01
Number of persons exposed to radiation during stops	10	10	20	10	20
Distance between container and exposed persons during stops (m)	10	10	10	10	10
Storage time (h/transport)	0	0	0	0	0
Number of persons exposed to radiation during storage	0	0	0	0	0
Distance between container and exposed persons during storage (	0	0	0	0	0
Convoy (persons)	8	8	8	8	8
Share of urban area transport during rush hour			0		0
Share of urban area transport in the centre			0,6		0,5
Share of transport on motorway	1	0	0,5	0	0
further information: Container CASTOR-VVER 440/84M (maximum loaded weight 140 t)					

Table 4. Initial data for the coastal transport route (continued), sections 6–10.

Route 1 (TR1)	**Mynämäki-Laitila-Rauma-Olkiluoto**				
(“Coastal route”)	(sections 11–15)				
Initial data	Myn-Lai	Lai(TA)	Lai-Rau	Rau(TA)	Rau-OL
	road	road	road	road	road
Length (km) in total 381	25	3	28	6	19
Traffic density in total (vehicles/h)	310	320	260	460	260
Accident frequency (1/km)	1.00-E07	5.00-E07	1.00-E07	5.00-E07	1.00-E07
Population density (persons/km2)	15	30	15	40	15
Transports per year	9	9	9	9	9
Containers per transport	1	1	1	1	1
Dose rate at 1 m (mSv/h)	0,05	0,05	0,05	0,05	0,05
Transport speed (km/h)	60	40	60	40	40
Number of transport personnel	2	2	2	2	2
Average distance between container and transport personnel (m)	10	10	10	10	10
Handling of containers (per transport)	0	0	0	0	1
Duration of stops (h/km)	0,005	0,01	0,005	0,01	0,005
Number of persons exposed to radiation during stops	10	20	10	20	10
Distance between container and exposed persons during stops (m)	10	10	10	10	10
Storage time (h/transport)	0	0	0	0	0
Number of persons exposed to radiation during storage	0	0	0	0	0
Distance between container and exposed persons during storage (	0	0	0	0	0
Convoy (persons)	8	8	8	8	8
Share of urban area transport during rush hour		0		0	
Share of urban area transport in the centre		0,5		0,1	
Share of transport on motorway	0	0	0	1	0

further information: Container CASTOR-VVER 440/84M (maximum loaded weight 140 t)

Table 4. Initial data for the coastal transport route (continued), sections 11–15.

Route 2 (TR2)	Hästholmen-Hyvinkää-Forssa-Loimaa-Olkiluoto				
("Inland route")					
Initial data	LO-Hyv	Hyv(TA)	Hyv-For	For(TA	For-OL
	road	road	road	road	road
Length (km) in total 352	112	5	85	12	138
Traffic density in total (vehicles/h)	30	200	50	200	30
Accident frequency (1/km)	1.00-E08	5.00-E07	5.00-E08	5.00-E07	1.00-E08
Population density (persons/km2)	15	50	20	75	20
Transports per year	9	9	9	9	9
Containers per transport	1	1	1	1	1
Dose rate at 1 m (mSv/h)	0,05	0,05	0,05	0,05	0,05
Transport speed (km/h)	35	20	35	20	35
Number of transport personnel	2	2	2	2	2
Average distance between container and transport personnel (m)	10	10	10	10	10
Handling of containers (per transport)	1	0	0	0	1
Duration of stops (h/km)	0,005	0,01	0,005	0,01	0,005
Number of persons exposed to radiation during stops	10	30	10	50	10
Distance between container and exposed persons during stops (m	10	10	10	10	10
Storage time (h/transport)	0	0	0	0	0
Number of persons exposed to radiation during storage	0	0	0	0	0
Distance between container and exposed persons during storage (	0	0	0	0	0
Convoy (persons)	8	8	8	8	8
Share of urban area transport during rush hour		0		0	
Share of urban area transport in the centre		0,2		0,5	
Share of transport on motorway	0,2	0	0,6	0	0,15

further information: Container CASTOR-VVER 440/84M (maximum loaded weight 140 t)

Table 5. Initial data for the inland route.

4.2.2 RADIATION DOSES FROM NORMAL TRANSPORTS

The dose rate outside the transport container is an essential piece of initial data when assessing the radiation doses caused by normal transports to the population and transport personnel. Section 4.1 of this report modelled the CASTOR 440/84M transport container in detail and calculated the dose rates outside the container at different fuel burn-up levels (50 MWd/kgU and 60 MWd/kgU).

This study conservatively uses the container dose rates calculated with the 60 MWd/kgU burn-up, so the selected dose rate describes the highest possible exposure of the population with certainty. Therefore, the selection covers a scenario in which fuel assemblies with the highest burn-up would be transported simultaneously inside the container in a transport batch.

For the RADTRAN model (Neuhauser, 1992) calculation, the dose rates selected based on the container's radiation dose results were 0.05 mSv/h for neutron radiation and 0.0007 mSv/h for photon radiation at a distance of 1 m from the container shell surface, with the total dose rate being 0.05 mSv/h (see Figure 15 in section 4.1.2). The values correspond to a burn-up of 60 MWd/kgU and the fuel being cooled for 20 years before being transported.

As mentioned previously in the report, according to the plans, the spent fuel from Loviisa will be placed in final disposal over the course of 11 years; accordingly, there would be an average of 9 road transports per year with one container. Figures 20 and 21 present the annual road transport doses incurred by the transport personnel, container handlers, population along the route and passengers of bypassed vehicles as well as the dose during temporary stops of transportation and the total dose.

The radiation dose rate outside the transport container, population density and traffic density along the route as well as the transportation speed (exposure time) are essential factors that affect the radiation dose to the population along the route. Both the coastal route (TR1) and inland route (TR2) run largely in sparsely populated areas such that there are no large population volumes in the immediate vicinity of the route. However, both routes involve passing through urban areas, which potentially causes exposure for a higher number of people compared to the traditional rural areas.

The traffic densities on various road sections are based on the Finnish Transport Infrastructure Agency's traffic volume map from 2020 (Finnish Transport Infrastructure Agency). The traffic density along the examined road transport

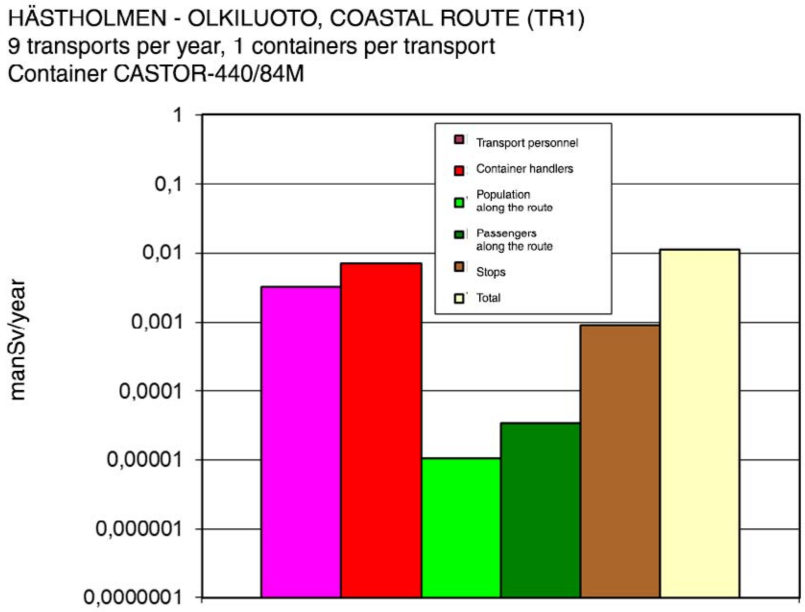
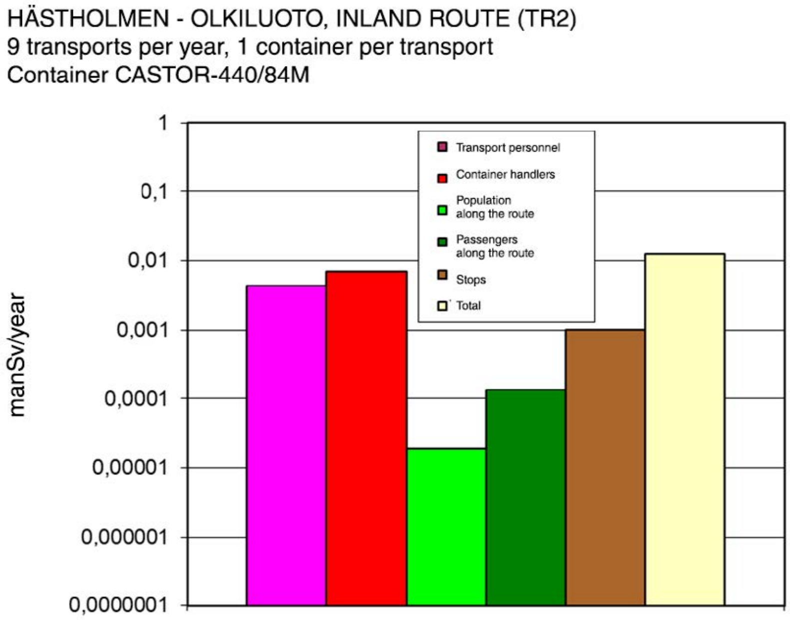
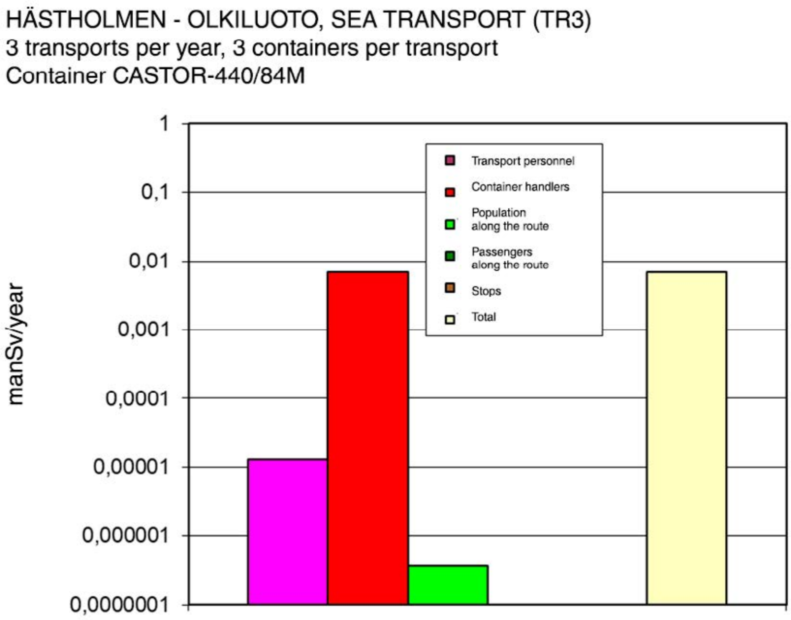


Figure 20. Radiation doses incurred on the coastal route.



■ **Figure 21.** Radiation doses incurred on the inland route



■ **Figure 22.** Radiation doses incurred for sea transports from Hästholmen to Olkiluoto.

routes varies between 100 and 60 000 vehicles/ day, depending highly on the area, road type and road section. The section with the highest traffic volumes is the E-18. In general, it is not favourable to conduct special transports during rush hours. Therefore, the calculations in this analysis use traffic densities during the transport that are slightly below the peak traffic levels.

In densely populated areas, most of the population will be located inside buildings and will, thereby, have various levels of protection from external radiation. The attenuation of radiation caused by this protection (protection factor for different building types) is taken into account in the RADTRAN calculations.

The coastal route allows for maintaining an effectively higher speed (shortening the transport time), resulting in slightly lower radiation doses

	(manSv/year)			
	Total population dose	Transport personnel dose	Container handlers' dose	Total
Coastal route by road	$9.6 \cdot 10^{-4}$	$3{,}2 \cdot 10^{-3}$	$6{,}9 \cdot 10^{-3}$	$1{,}1 \cdot 10^{-2}$
Inland route by road	$1{,}2 \cdot 10^{-3}$	$4{,}4 \cdot 10^{-3}$	$6{,}9 \cdot 10^{-3}$	$1{,}3 \cdot 10^{-2}$
Sea transport from Hästholmen	$4{,}1 \cdot 10^{-7}$	$1{,}3 \cdot 10^{-5}$	$6{,}9 \cdot 10^{-3}$	$6{,}9 \cdot 10^{-3}$
Sea transport from the port of Valko	$4{,}9 \cdot 10^{-5}$	$2{,}6 \cdot 10^{-4}$	$1{,}0 \cdot 10^{-2}$	$1{,}0 \cdot 10^{-2}$

Table 6. A summary of the radiation doses by route and mode of transport. It is assumed that a total of 9 containers per year are transported from Hästholmen to Olkiluoto (9x1 container by road, 3x3 containers by sea). The total population dose is the combined figure of the doses incurred by the population along the route and passengers of bypassed vehicles as well as the population doses caused by stops.

for the personnel participating in the transport compared to the inland route (Figures 20 and 21). The total radiation doses are 0.011 manSv for the coastal route and 0.013 manSv for the inland route.

When comparing the modes of transport, ship transport leads to clearly lower population radiation doses (Figure 22), as there is hardly any population that could be exposed in the immediate vicinity of the transport. Similarly, during the transport, the personnel is located far away from the containers, so they only accumulate a minor radiation dose. The estimated annual total radiation dose for ship transports that depart directly from Hästholmen is 0.007 manSv. Transports from Hästholmen via the port of Valko to Olkiluoto would result in a total radiation dose of 0.01 manSv, as the dose incurred by the handlers, transport personnel and population will grow due to the road transport section from the nuclear power plant to the port of Valko.

4.3 TRAFFIC ACCIDENT SCENARIOS

4.3.1 HYPOTHETICAL ACCIDENT SCENARIOS AND RELEASES

A transport container may collide with an obstacle at various angles, which is relevant for the failure probability of the fuel rods. In collision scenarios, the modes of impact are (Figure 23):

- Impact with end first
- Impact with the container's corner first
- Impact with side first

In addition to these basic types, a practical collision scenario often involves various combinations, such as an impact corner first and then immediately being thrown side first against an obstacle.

If the load environment causes stresses to the fuel rods inside the container and, in particular, their protective cladding, that exceed the maximum allowed stress values for the cladding, the fuel rods will become damaged and the protective cladding will lose its integrity inside the transport container.

In terms of consequence analyses, the damage suffered by the fuel rods can be viewed realistically or conservatively. There is research data available on the conditional damaging probabilities of different fuel assembly types (Foadian et. al. 1992), based on which a realistic magnitude for the proportion of damaged rods can be determined. The conservative approach is an ANSI-compliant (ANSI N14.5 1987) pessimistic assumption that 100% of the rods become damaged. In this case, all the rods inside the container lose their integrity and the radionuclides in the rods' gas space can be released into the free space inside the container.

The current plan is to use a gas-cooled CASTOR 440/84M transport container for transporting spent fuel from Loviisa. Before transportation, the transport container is dried and filled with inert helium gas. This study makes a conservative assumption that the fuel rod cladding temperature during the transport is 300oC.

The hypothetical accident scenarios examined in this study, A, B, C and D, are described in

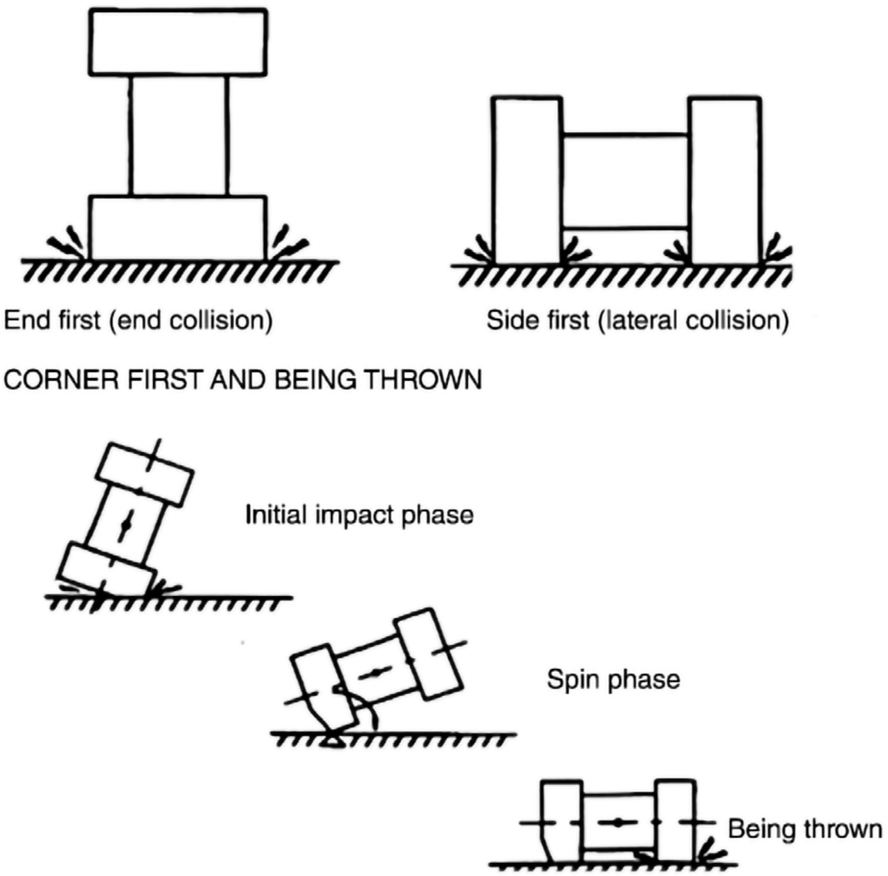


Figure 23. Container's modes of impact with an obstacle (Sanders et. al. 1992)

Table 7. In a realistic scenario (A), only a small proportion of the rods become damaged, and noble gases and other volatile substances are assumed to be released from the rods' gas space into the container according to the release proportions in Table 8. Gaseous substances and particles are further assumed to be released into the environment through a damaged cover section, resulting in a radioactive release (Table 9). The particle release proportions are based on experimental studies (Sanders et. al 1992, Colle J.Y. et. al. 2006). It is likely that some of the particles settle on and are held by the container's inner surfaces. The bases of release are also discussed more extensively in previous studies conducted for Posiva (Suolanen et. al. 1999, Suolanen et. al. 2004) and their reference reports.

In a realistic thermal scenario (B), a fire that occurs outside the container in connection with the collision will gradually increase the temperature inside the container as well, which may accelerate the release of substances from the container into the environment. The rise in air temperature outside the container will result in the thermal lift of the release plume, i.e. increase the effective release height.

In the ANSI (American National Standards Institute) scenario (C), a conservative assumption is made that all the fuel rods inside the transport container become damaged. The external conditions are otherwise the same as in scenario A.

In the ANSI thermal scenario (D), the effects of an external fire are considered in terms of a release and emission as in scenario B.

The releases have been calculated based on fuel with a conservative burn-up of 60 MWd/kgU and a cooling time of 20 years (Table 10).

4.3.2 INITIAL DATA FOR SPREADING CALCULATIONS AND DOSE CALCULATIONS

The spreading of the release and radiation doses in the environment have been calculated with VTT's ARANO model, which was originally developed for calculating the effects of reactor accidents. It is also well suited for the spreading

Accident scenario	Ident-ifier	Thermal external conditions	Proportion of rods damaged inside container	Release into container from damaged rods	Proportion of particulate* release into the environment	Release height
REALISTIC COLLISION	A	normal	$3 \cdot 10^{-3}$	See Table 8	0,1	20 m
REALISTIC THERMAL COLLISION	B	fire 800oC	$3 \cdot 10^{-3}$	”	0,5	80 m
ANSI COLLISION	C	normal	1,0	”	0,1	20 m
ANSI THERMAL COLLISION	D	fire 800oC	1,0	”	0,5	80 m

*) It is assumed that fission product gases are not held inside the container, so their proportion of release into the environment is 1.0 in all the accident scenarios.

Table 7. Definitions of accident scenarios.

Nuclide	VVER fuel from Loviisa	
	Temperature (oC)/Burn-up (MWd/kgU)	
	300/60	500/60
H-3	0,5	0,5
Kr-85	0,072	0,072
I-129	0,032	0,032
Cs-134	0,0001	0,00011
Cs-137	0,0001	0,00011
Other	0,00003	0,00003

Table 8. Proportions of release from damaged fuel rods into the container (as a proportion of each rod's full inventory). The examined temperatures are 300oC (no fire) and 500oC (fire).

Gas-cooled CASTOR-VVER-440/84M (84 assemblies/container, 120 kgU/assembly, in total approximately 10 tU/container)				
Nuclide	Releases in accident scenarios (Bq)			
	A	**B**	**C**	**D**
	H=20	H=80	H=20	H=80 m
	T=300 °C	T=500 °C	T=300 °C	T=500 °C
	t=30 min	t=10 min	t=30 min	t=10 min
H-3	$1,9 \cdot 10^{11}$	$1,9 \cdot 10^{11}$	$6,5 \cdot 10^{13}$	$6,5 \cdot 10^{13}$
Kr-85	$3,4 \cdot 10^{11}$	$3,4 \cdot 10^{11}$	$1,1 \cdot 10^{14}$	$1,1 \cdot 10^{14}$
Sr-90	$2,6 \cdot 10^{8}$	$1,3 \cdot 10^{9}$	$8,4 \cdot 10^{10}$	$4,2 \cdot 10^{11}$
I-129	$1,7 \cdot 10^{6}$	$1,7 \cdot 10^{6}$	$6,0 \cdot 10^{8}$	$6,0 \cdot 10^{8}$
Cs-134	$5,0 \cdot 10^{6}$	$2,7 \cdot 10^{7}$	$1,7 \cdot 10^{9}$	$9,1 \cdot 10^{9}$
Cs-137	$1,3 \cdot 10^{9}$	$7,3 \cdot 10^{9}$	$4,4 \cdot 10^{11}$	$2,4 \cdot 10^{12}$
Pu-238	$2,3 \cdot 10^{7}$	$1,2 \cdot 10^{8}$	$7,8 \cdot 10^{9}$	$4,0 \cdot 10^{10}$
Pu-239	$1,4 \cdot 10^{6}$	$7,0 \cdot 10^{6}$	$4,5 \cdot 10^{8}$	$2,3 \cdot 10^{9}$
Pu-241	$2,7 \cdot 10^{8}$	$1,4 \cdot 10^{9}$	$9,2 \cdot 10^{10}$	$4,7 \cdot 10^{11}$
Am-241	$1,7 \cdot 10^{7}$	$8,1 \cdot 10^{7}$	$5,6 \cdot 10^{9}$	$2,8 \cdot 10^{10}$
Cm-244	$2,9 \cdot 10^{7}$	$1,5 \cdot 10^{8}$	$9,7 \cdot 10^{9}$	$4,9 \cdot 10^{10}$

Table 9. Activity releases into the environment for a gas-cooled CASTOR-VVER-440/84M transport container in postulated accident scenarios A, B, C and D. Fuel burn-up 60 MWd/kgU, cooling time 20 years.

Nuclide	T½ (year)	VVER-440 (Bq/tU)	In transport container (Bq/10 tU)
H-3	12.28	$1,28\cdot10^{13}$	$1,29\cdot10^{14}$
C-14	5730	$1,93\cdot10^{11}$	$1,95\cdot10^{12}$
Kr-85	10,72	$1,55\cdot10^{14}$	$1,56\cdot10^{15}$
I-129	1,6E7	$1,86\cdot10^{9}$	$1,88\cdot10^{10}$
Cs-134	2,062	$1,63\cdot10^{13}$	$1,64\cdot10^{14}$
Cs-137	30,17	$4,40\cdot10^{15}$	$4,44\cdot10^{16}$
Sr-90	28,6	$2,77\cdot10^{15}$	$2,79\cdot10^{16}$
Ru-106	1,02	$4,35\cdot10^{10}$	$4,39\cdot10^{11}$
Ce-144	0,78	9,65·108	$9,74\cdot10^{9}$
Pu-238	87,75	$2,60\cdot10^{14}$	$2,62\cdot10^{15}$
Pu-239	24131	$1,52\cdot10^{13}$	$1,53\cdot10^{14}$
Pu-241	14,3	$3,03\cdot10^{15}$	$3,06\cdot10^{16}$
Am-241	432,2	$1,84\cdot10^{12}$	$1,86\cdot10^{15}$
Cm-244	18,11	$3,21\cdot10^{14}$	$3,24\cdot10^{15}$

Table 10. Intrinsic radioactivity (Bq/tU) and total radioactivity in transport container (Bq/10 tU) of nuclides significant in terms of environmental impacts for VVER fuel from Loviisa. Burn-up 60 MWd/kgU, cooling time 20 years. (Anttila 2005, Leppänen 2017, Karvonen 2021).

calculation of other source terms. In terms of calculation principle, ARANO is a straightforward Gaussian model that has been used particularly for PSA[1] level 3 analyses.

The spreading scenarios of accidental releases (A, B, C and D) are individual representative spreading scenarios; on the other hand, expected radiation dose values have been calculated, weighing long-term spreading data with the probability of various weather conditions. Thus, the calculations have considered the uncertainty related to weather conditions during the spreading of a radioactive plume.

As the statistical weather data for the ARANO model, this study used the data measured from the Loviisa nuclear power plant weather mast (Jurvanen 2021), which is considered to represent well enough the wind direction distribution of the Southern coastal area (Figure 24). Therefore, the weather data is applicable to a situation in which a radioactive release occurs on the coastal transport route in a dense residential and/or industrial area.

1 Probabilistic Safety Assessment (PSA) is a method generally used for accident analyses of nuclear power plants and other nuclear equipment. A level 3 PSA analyses the spreading of a radioactive release and the resulting radiation doses in the environment on the basis of probabilities, taking into account the probability distributions related to various weather parameters.

A radiation dose is assumed to comprise three exposure routes: direct external radiation from the plume, direct external radiation from the fallout and internal exposure due to inhaled radioactive material. Exposure from nutrition has not been discussed as the consumption of contaminated foods could be restricted, if necessary. Furthermore, the dusting of radioactive particles that settle on the ground has not been discussed as it is generally considered to be of minor significance in the Finnish conditions due

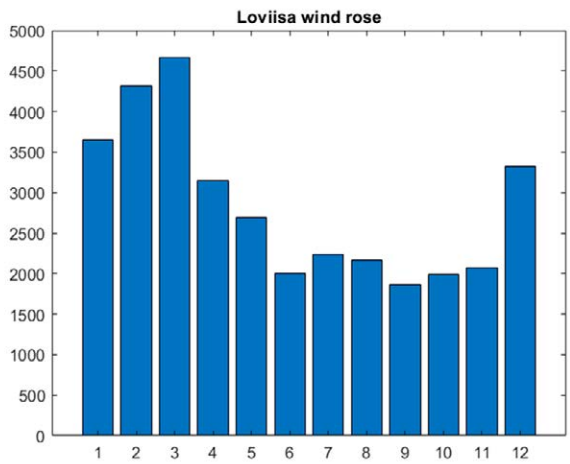


Figure 24. Wind direction distribution based on measurements from the Loviisa weather mast. The presented Arano sectors 1–12 correspond to the spreading directions equivalent to the “clock face”.

to the ground vegetation and seasonal variation. The presented doses are effective doses that describe the biological effects that radiation has on people.

The used shielding factors are 1.0 for a plume dose and 0.3 for a fallout dose. For a plume dose, 1.0 conservatively means that the subject is located in an open outdoor area throughout the plume passing over. The fallout dose is accumulated over the course of a longer integration period, and the factor 0.3 takes into account that the subject spends part of the time inside different types of buildings. The value used for the breathing rate is conservatively quite high at 2.8e-4 m^3/s = 16.8 dm^3/min. The nuclides causing an inhalation dose are bound to the body as the plume passes over but provide an accumulated dose over a longer time ("dose commitment").

4.3.3 RADIATION DOSES FROM ACCIDENT SCENARIOS

As described above (Section 4.3.2), the radiation doses incurred by a person located within the spreading environment have been calculated on somewhat conservative grounds. Shielding during the plume passing over and the breathing rate used for calculating the inhalation dose are based on a conservative approach. However, a person is assumed to live according to the normal daily schedule (10% of the day outdoors) and live in a normal apartment (40% in low-rise buildings and the rest of the population in blocks of flats) with conventional shielding provided by the structures against the external radiation caused by a fallout.

Figures 25–30 depict the radiation doses cased by the spreading of a release during individual neutral weather conditions (stability D) distances of 0.1 km, 1 km, 5 km, 20 km, 40 km and 100 km. In addition, the results for spreading during fair weather or rain are presented.

In the case of a realistic accident scenario (A), the monthly committed dose equivalents of individuals (in fair weather) near the transport container are as follows: 1.3 μSv (0.1 km) and 0.13 μSv (1 km). For spreading during rain, the values are: 1.5 μSv (0.1 km) and 0.17 μSv (1 km).

In a realistic thermal scenario (B), the release height is higher (80 m) and the dose maximum is observed farther than in scenario A. The monthly committed dose equivalents (in fair weather) are as follows: 0.18 μSv (0.1 km) and 0.28 μSv (1 km).

If all the fuel rods became damaged (ANSI scenario (C)), the monthly committed dose equivalents would naturally be much higher: 0.4 mSv (0.1 km) and 0.04 mSv (1 km). For spreading during rain, the values are: 0.5 mSv (0.1 km) and 0.05 mSv (1 km).

In a thermal release scenario, the dose maximum of the ANSI scenario is, similarly, observed at a distance of 1 km, and with a one-month integration time, the total individual dose (in fair weather) is 0.09 mSv.

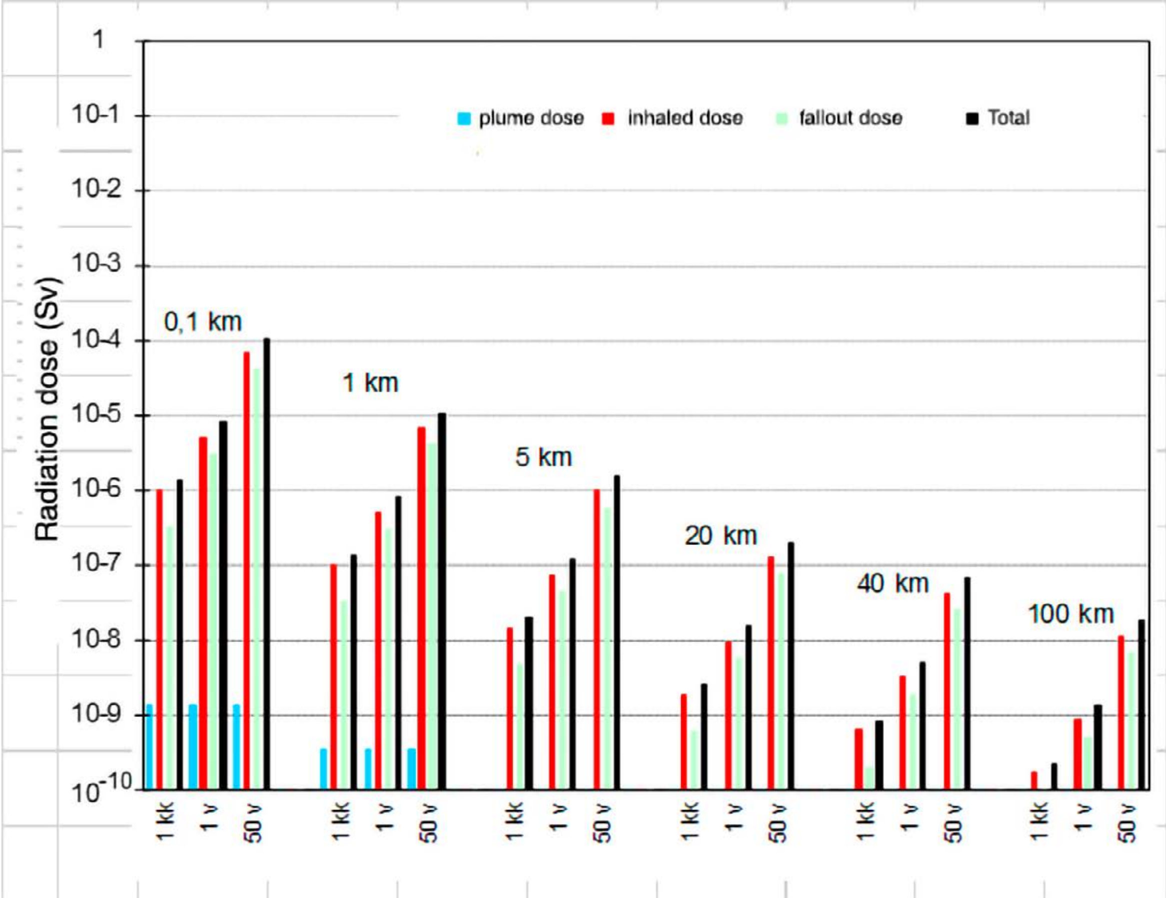
Over a very long 50-year integration time, the committed dose equivalent for spreading in fair weather is 0.01 mSv in scenario A and 3.6 mSv in scenario C at a distance of 1 km.

To summarise, it can be stated that the radiation doses in realistic accident scenarios would remain very small even near the transport container, and the calculated annual doses are clearly below e.g. the allowed maximum annual dose of 0.1 mSv.

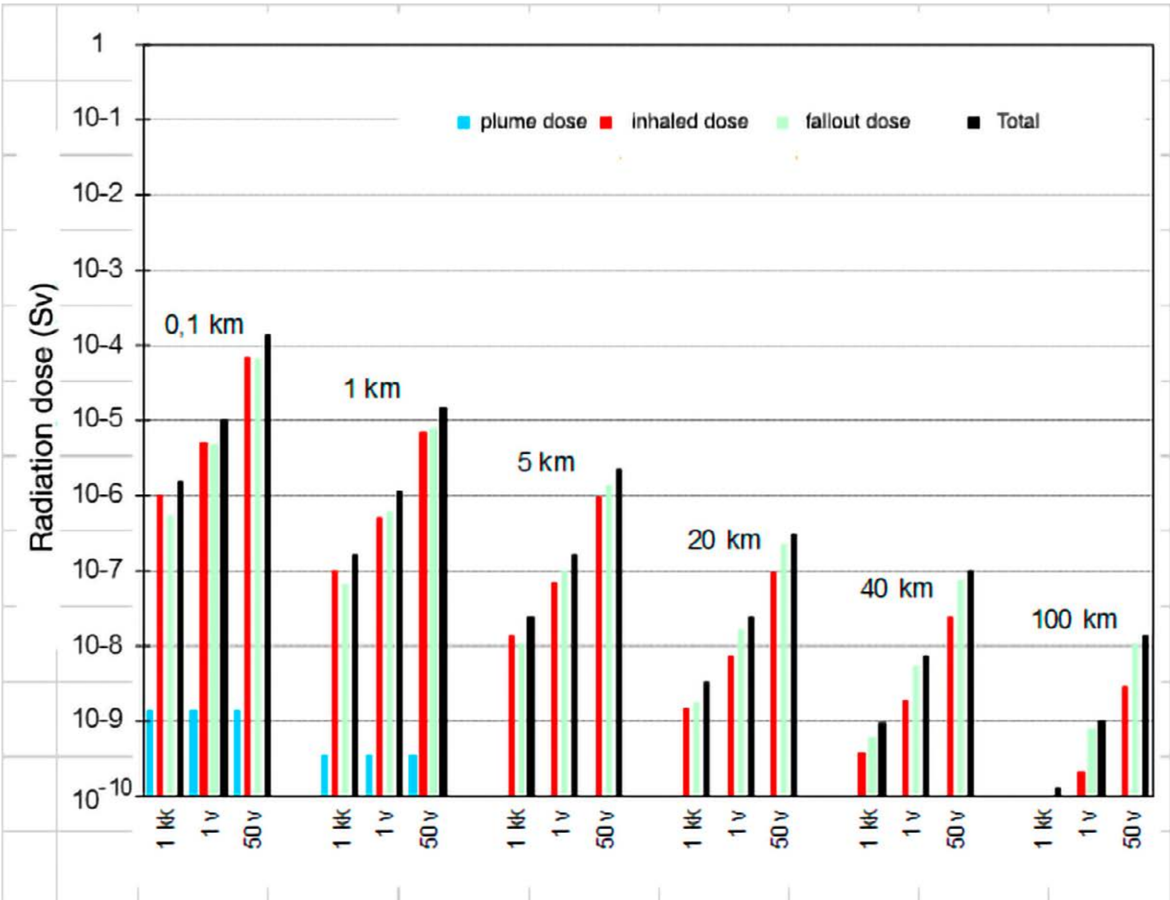
Figures 31 to 36 present the expected dose values as a function of distance, and they depict the expected doses more truthfully in that they take into account the distribution of actual weather conditions. Each figure presents expected dose value graph (black line) and, for reference, the dose from a single spreading scenario (blue line) for spreading during rain.

In general, it can be observed that the expected dose values are lower than the dose from an individual weather scenario. In a realistic accident scenario (A), the maximum dose value is 0.07 μSv (0.1 km), and in case all the rods become damaged (ANSI scenario (C)), it is 0.02 mSv (0.1 km). The expected value is affected by the fact that, during calculations, the wind does not even reach the target sector in individual cases, so in most directions the dose will be zero. For the final expected value, ARANO considers all the directions, the actual wind direction and the other weather parameters.

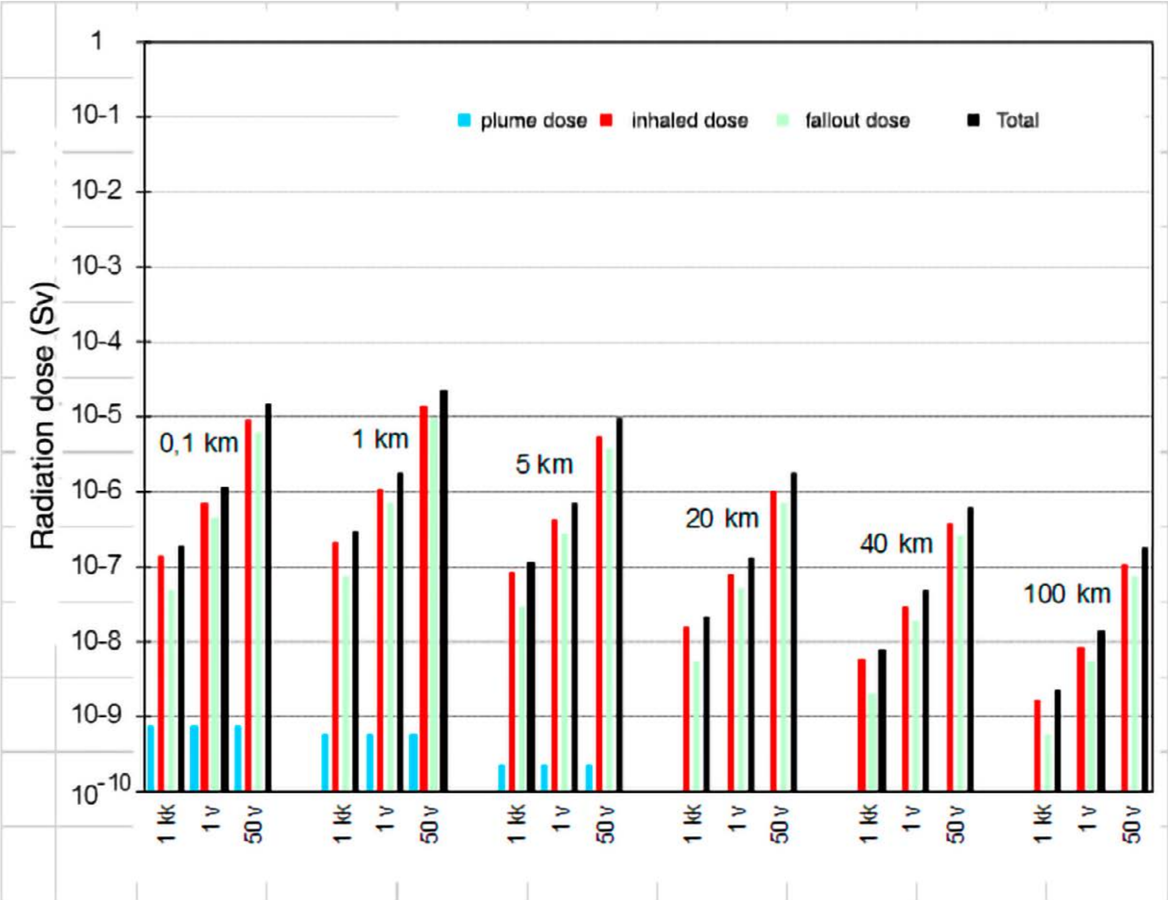
Therefore, the expected radiation doses remain small during the acute phase but, with very long integration times, the committed dose equivalent would reach the dose limit level or exceed it slightly.



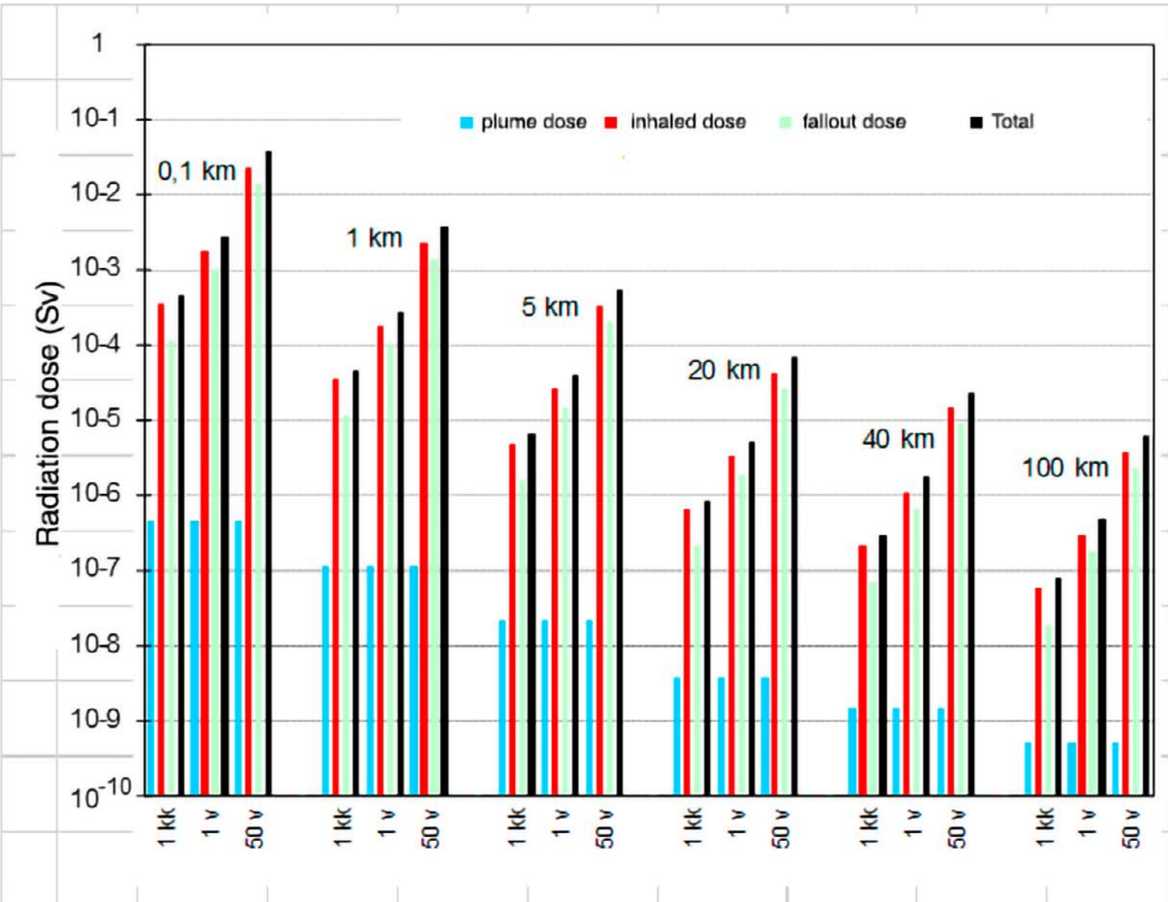
■ **Figure** 25. Dose as a function of distance in the realistic release scenario (A), stability D, fair weather.



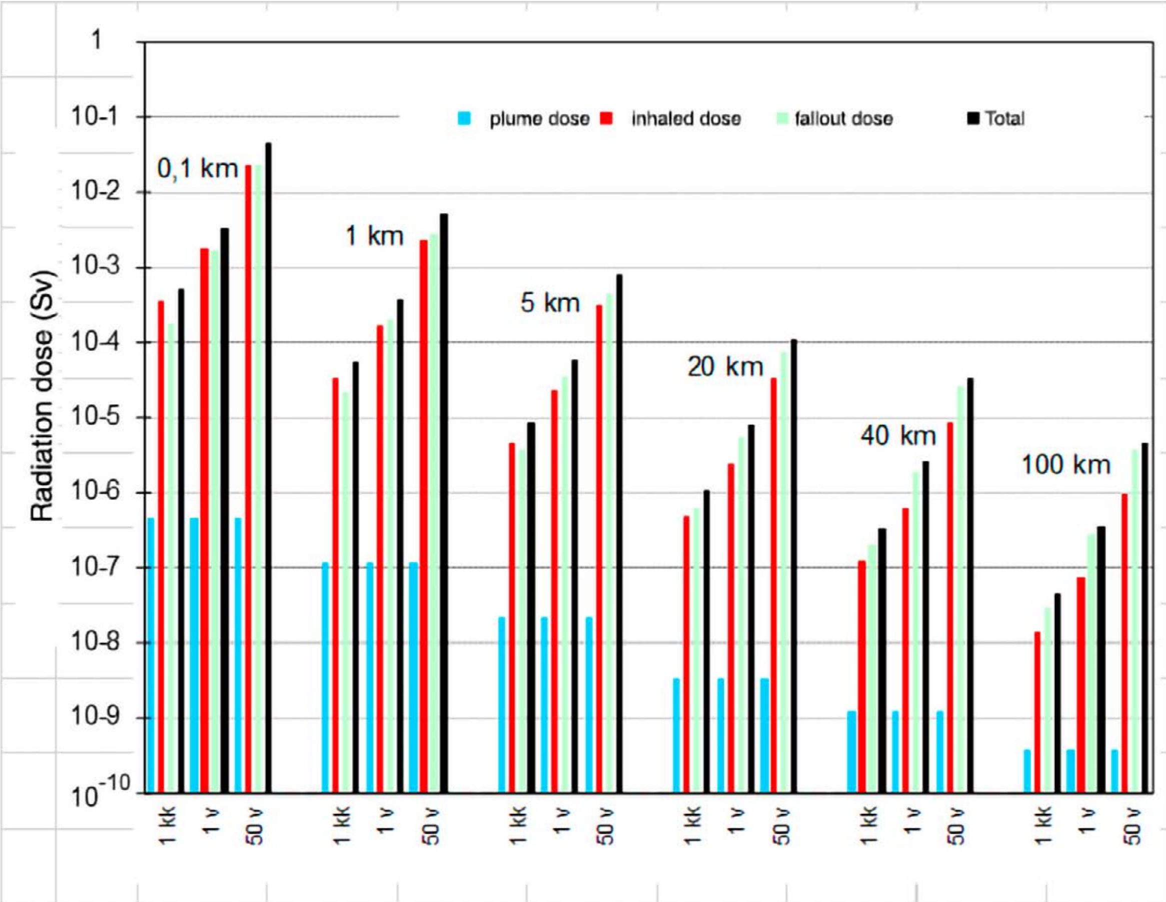
■ **Figure** 26. Dose as a function of distance in the realistic release scenario (A), stability D, rain.



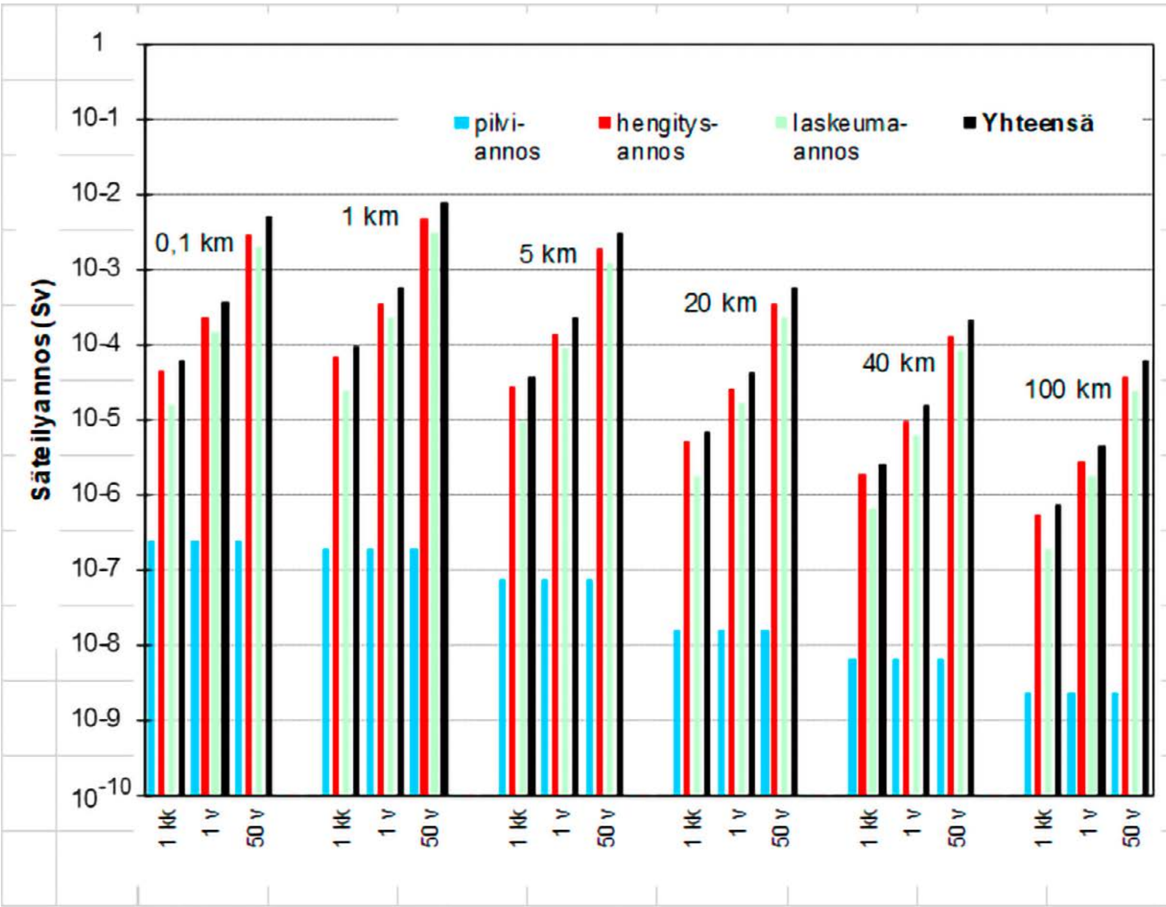
■ **Figure** 27. Dose as a function of distance in the realistic thermal release scenario (B), stability D, fair weather



■ **Figure** 28. Dose as a function of distance in the ANSI release scenario (C), stability D, fair weather.



■ **Figure** 29. Dose as a function of distance in the ANSI release scenario (C), stability D, rain.



■ **Figure** 30. Dose as a function of distance in the ANSI thermal release scenario (D), stability D, fair weather.

EXPECTED RADIATION DOSE VALUES (black graphs)

1-month integration time (Figures: 31, 33 and 35)

50-year integration time (Figures: 32, 34 and 36)

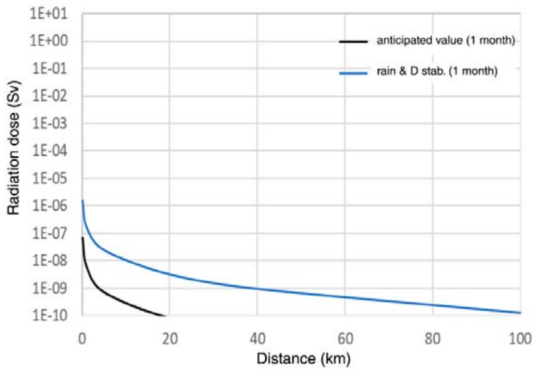


Figure 31. Combined dose from plume, inhalation and fallout in the realistic release scenario (A).

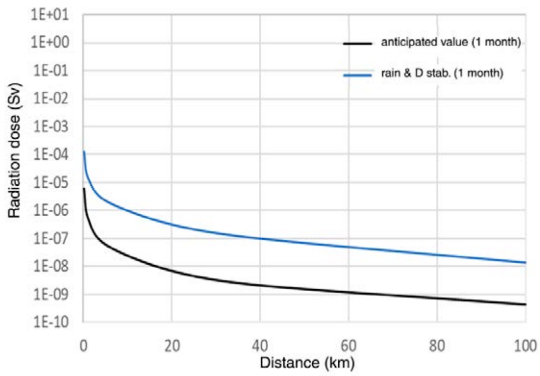


Figure 32. Combined dose from plume, inhalation and fallout in the realistic release scenario (A).

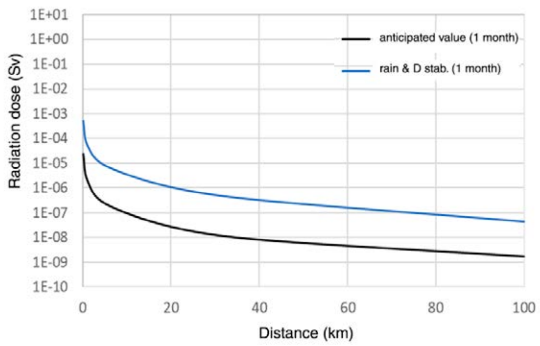


Figure 33. Combined dose from plume, inhalation and fallout in the ANSI release scenario (C).

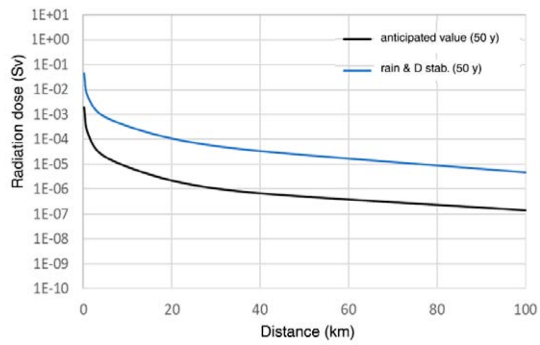


Figure 34. Combined dose from plume, inhalation and fallout in the ANSI release scenario (C).

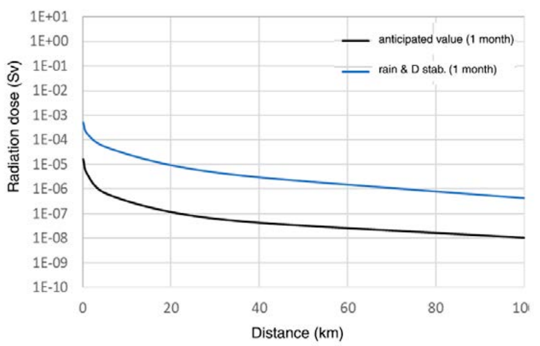


Figure 35. **Combined dose from plume, inhalation and fallout in the ANSI thermal release scenario (D).**

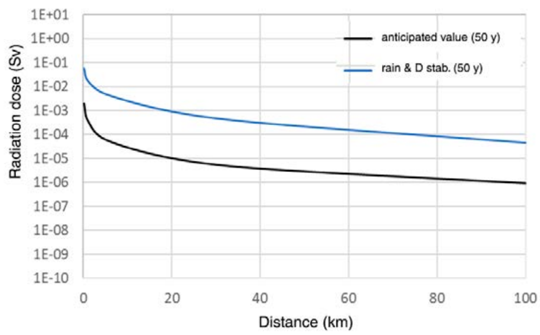


Figure 36. Combined dose from plume, inhalation and fallout in the ANSI thermal release scenario (D).

In a summary review of the effects of accident scenarios, the results from all scenarios (A, B, C, D) can be presented together with the generally applied radiation dose limit (Figure 37). It can be observed that, in the realistic accident scenarios (A, B), the radiation dose is clearly below the dose limit. Furthermore, the figure shows the effect of the release being thermal (scenarios B, D), which causes the fallout and actual doses farther from the source to be higher compared to a conventional release without the effects of a fire.

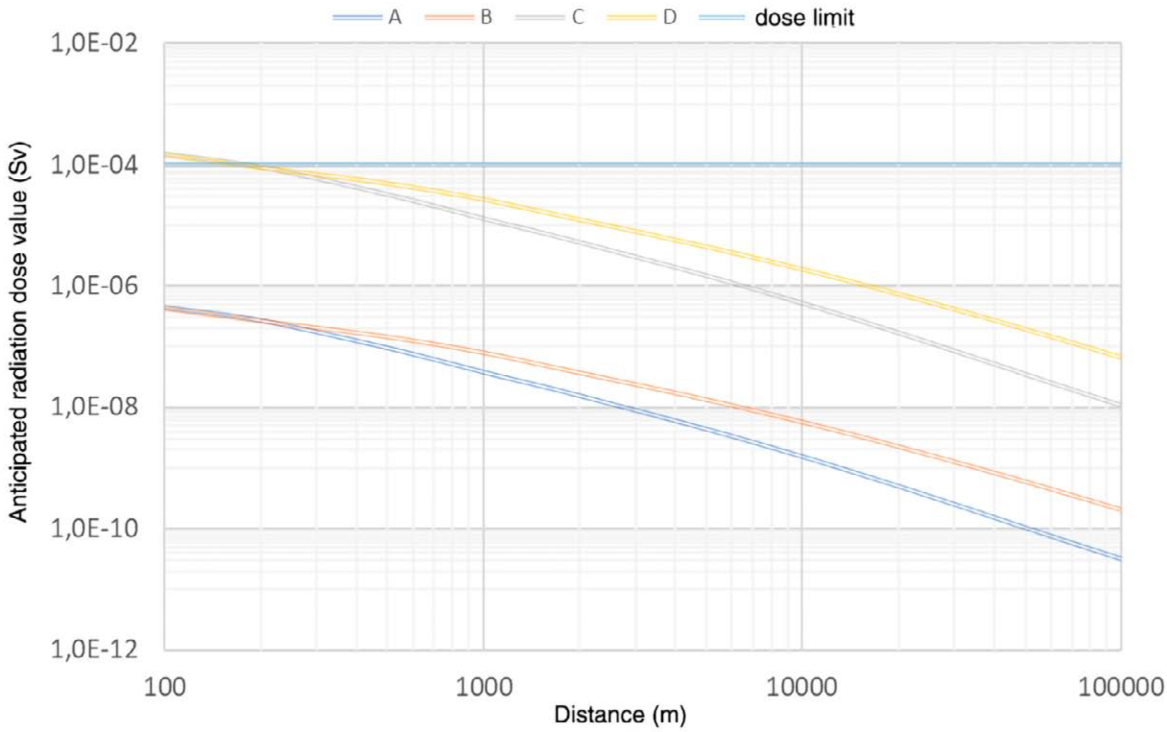


Figure 37. A summary of the expected values for individual radiation doses in accident scenarios A, B, C and D. The figure also presents the maximum allowed radiation dose, or dose limit, which is generally applied to accident scenario reviews (0.1 mSv/year). The dose limit would be exceeded only in the most severe scenario (D, 100% of the fuel rods becoming damaged in a collision) in the vicinity. Realistic accident scenarios remain clearly below the dose limit.

5 SUMMARY

This study examined the transports of spent nuclear fuel accumulated at the Loviisa nuclear power plant during operation to the Olkiluoto disposal facility in terms of radiation safety. The special areas of the study were the calculation of the transport container's dose rate and an evaluation of the dose effects resulting from normal transports and hypothetical traffic accident scenarios.

The work involved modelling in detail the gas-cooled CASTOR-440/84M transport container considered for the transports and conducting radiation protection and dose rate calculations with the Serpent model for determining the dose rate outside the container at burn-up values of 50 MWd/kgU and 60 MWd/kgU. According to the calculations, the total dose rate at a 2-m distance from the container shell is 0.03 mSv/h, which is clearly below the dose limit of 0.1 mSv/h presented by the IAEA. The total dose is dominated by neutron radiation caused by spontaneous fission, and photon radiation has little significance in terms of the total dose.

The study examined both coastal and inland road transport route alternatives. Furthermore, sea transports by ship from the port of Valko, Loviisa and directly from Hästholmen to Olkiluoto Port were examined.

In normal transports, the highest radiation doses are incurred by personnel during the handling of the transport container, and the radiation doses incurred by the population during the transport are lower. In road transports, the annual total radiation dose based on a conservative analysis is approximately 0.01 manSv for the coastal route and approximately 0.013 manSv for the inland route. Due to the shorter exposure time, the radiation dose incurred by the personnel is slightly lower for the coastal route compared to transports that use the inland route. In sea transports, the total annual radiation dose is 0.01 manSv for transports via the port of Valko and 0.007 manSv for transports that depart directly from Hästholmen. In the Valko option, the road transport section from the nuclear power plant to the port increases the number of container handling steps and the radiation dose.

Hypothetical traffic accident scenarios have been reviewed in terms of a realistic collision, realistic thermal collision (collision and fire) and 100% of the fuel rods becoming damaged. The spreading of a radioactive release occurring in the different scenarios and the resulting doses have been calculated by using VTT's ARANO model for individual weather conditions and expected radiation doses; the expected dose values as a function of distance have been determined by using weighing based on the probability of different weather conditions. The calculations have also considered the effects of fair weather or rain on the fallout and radiation doses.

In a realistic accident scenario, an individual's annual dose in a single neutral weather scenario remains at the level of 1 µSv at a distance of 1 km from the transport container. A fire in connection with a collision (thermal scenario) increases the release height and results in the dose maximum being observed further compared to a scenario without a fire. In a realistic accident scenario, the individual dose remains clearly below the annual dose limit of 0.1 mSv.

Even in a pessimistic scenario where all the rods become damaged, immediate health effects to the population are not expected, even if the radiation doses accumulated due to the fallout were to reach a significant level in the long term.

Taking into account the actual distribution of the weather conditions, the magnitude of the obtained expected values for radiation doses is approximately one tenth of the values for individual spreading scenarios.

To summarise, as a result of normal transports or a hypothetical realistic accident scenario, the transports of spent fuel do not cause a significantly elevated health risk to the population resulting from radiation exposure.

REFERENCES

ANSI, American Nuclear Society, “American National Standard for Neutron and Gamma-Ray Flux-to-Dose-Rate Factors”, ANSI/ANS-6.1.1-1977, 1977.

ANSI N14.5-1987, American Nuclear Society, “American national standard for radioactive materials – leakage tests on packages for shipment”. New York, American National Standards Institute.

Capacent, Selvitys käytetyn ydinpolttoaineen kuljetuksesta Loviisasta Olkiluotoon, 2016.

Colle, J. Y., Hiernaut, J.-P., Papaioannou, D., Ronchi, C., Sasahara, A., Fission product release in high-burn-up UO2 oxidized to U3O8. Journal of Nuclear Materials 348, 2006, pp. 229-242.

GNS, 2014, CASTOR casks for the storage and transport of spent nuclear fuel. GNS-POSIVA-Fortum-TVO meeting, 21.10.2014

GNS, CASTOR 440/84M, 2017.

Hubbell, J. H. and Seltzer, S.M. Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients, 2004. (version 1.4). [online, access 3.3.2021, http://www.nist.gov/pml/data/xraycoef/]

IAEA 2018. Regulations for the Safe Transport of Radioactive Material, 2018 Edition. Specific Safety Requirements No. SSR-6 (Rev. 1). IAEA Safety Standards for protecting people and the environment, Vienna.

International Maritime Dangerous Goods (IMDG) Code: 2010 Edition, International Maritime Organization (IMO).

J. Leppänen, et al. - The Serpent Monte Carlo code: Status, development and applications in 2013. Annals of Nuclear Energy, 8:142-150, 2015

Jaakko Leppänen, Evaluation of radionuclide inventories in fuel and structural materials for TURVA-2020: Part II, Customer Report VTT-CR-05712-17, Espoo, 2017.

Jani Huttunen, Olli Nummi and Barbara Pastina, Source Terms for the Safety Case in Support of the Operating Licence Application, Posiva, 2021. (To be published.)

Juha-Pekka Jurvanen, Henkilökohtainen konsultaatio Posiva toimeksiantoon, 2021.

Karvonen, P., Kapselointi- ja loppusijoituslaitoksen normaalikäytön sekä käyttöhäiriö- ja onnettomuusanalyysien radioaktiivisten aineiden lähdetermi, NUCL-4394, Fortum, 2021.

Kärkkäinen & Karvonen, Kapselointilaitoksen säteilylaskenta, Osa 3: Kuljetussäiliön siirtokäytävä ja varastopaikka, NUCL-3792, LP-00013329, 2018.

Koskivirta O., Käytetyn polttoaineen kuljettaminen Loviisan voimalaitokselta Eurajoen

Olkiluotoon kapselointia ja loppusijoittamista varten; toteutustapaselvitys, Fortum, 2012.

Liikenne- ja viestintäministeriön asetus (1253/2002) erikoiskuljetuksista ja erikoiskuljetusajoneuvoista annetun liikenneministeriön päätöksen muuttamisesta.

Liikenne- ja viestintäviraston määräys, Vaarallisten aineiden kuljetus tiellä, TRAFICOM/82133/03.04.03.00/2019.

Neuhauser K. S. & Kanipe F. L., RADTRAN 4, User Guide. Albuquerque, SAND89-2370, 1992.

NIST Standard Reference Database 126, Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients, https://www.nist.gov/pml/x-ray-mass-attenuationcoefficients (accessed on May 6th 2019)

P. Juutilainen & S. Häkkinen, Impact of Fuel Type and Discharge Burnup on Source Term, Proceedings of the International Conference Nuclear Energy for New Europe, Portoroz, Slovenia, September 9–12, 2019

PNNL, Pacific Northwest National Laboratory, Compendium of Material Composition Data for Radiation Transport Modeling, PNNL-15870 Rev. 1, 2011

Sanders, T. L., Seager, K. D., Rashid, Y. R., Barrett, P. R., Malinauskas, A. P., Einziger, R. E., Jordan, H., Duffey, T. A., Sutherland, S. H. & Reardon, P. C. . A method for determining the spent-fuel contribution to transport cask containment requirements. Sandia National Laboratories, Albuquerque, U.S., SAND90-2406, 1992, 512 p.

SKB, Svensk Kärnbränslehantering AB.

Suolanen, V., Lautkaski, R. & Rossi, J., Käytetyn ydinpolttoaineen kuljetusten terveysriskien arviointi, POSIVA 99-17, 139 s., Helsinki, 1999.

Suolanen V., Lautkaski R., Rossi J., Nyman T., Rosqvist T. & Sonninen S., Käytetyn ydinpolttoaineen kuljetusriskitarkastelun päivitys, POSIVA 2004-04, ISBN 951-652-130-4, Olkiluoto, 2004.

Suomen asukasluvut kunnittain, Väestörekisterikeskus 2012.

Tietilastoja 2010, Liikenneviraston tilastoja 6/2011.

Valtioneuvoston asetus vaarallisten aineiden kuljetuksesta tiellä (194/2002), laki 719/1994.

Väyläviraston liikennemääräkartta vuodelta 2020.

Ydinenergia-asetus (161/1988).

Ydinenergialaki (990/1987).

YVL C.5 Ydinvoimalaitoksen valmiusjärjestelyt. 20.1.2020.

YVL D.2 Ydinaineiden ja jätteiden kuljetus. 15.5.2019.

13

REPORT ON THE CHANGES MADE TO THE FINAL DISPOSAL CONCEPT

Photo: Posiva Oy

REPORT ON THE CHANGES MADE TO THE FINAGL DISPOSAL CONCEPT

BACKGROUND

One condition for the construction licence of an encapsulation plant and disposal facility was the submittal of a report on the changes made to the final disposal concept in connection with the operating licence application. This report explains the changes that have been made to the concept after the construction licence application. According to the current plans, final disposal operations will be carried out for approximately one hundred years. As the Nuclear Energy Act requires following the development of technology and, thereby, adopting more effec-tive and safer technologies, Posiva's current plans will undergo plant modifications over the course of the final disposal and, due to the long time span of final disposal, there might be changes in the concept as well. Posiva assesses the safety of future plant modifications and concept changes under the surveillance of the Radiation and Nuclear Safety Authority (STUK).

Posiva has change management processes in place. Therefore, each change made in the planning automatically undergoes change evaluations in the organisation, in order to assess the effects of the change on the different aspects of safety:

- Significance for nuclear safety
- Significance for radiological safety
- Long-term safety
- Effect on security arrangements and data security
- Effect on fuel data management
- Effect on nuclear safeguards
- Assessment of human and organisational factors
- Effect of the changes on the licence application documentation

As part of change management, it is also assessed whether the change has project-level implications. They will be processed separately as project-guiding decisions (HOP), which will also undergo the safety assessments present-ed hereinabove. Some of them may also have effects on the concept presented in the construction licence appli-cation, but most of them will not cause any changes as they are related to the concept's planning, which will be specified over time.

POSIVA'S PROJECT-GUIDING DECISIONS

Below are Posiva's project-guiding decisions after the submission of the construction licence application and after receiving the construction licence, as well as an assessment of their effects on the concept.

The following project-guiding decisions were made after the submission of the construction licence application; they were already considered in STUK's safety assessment of the construction licence application:

1. Deposition tunnels' depth level and vehicle connection routes. This project-guiding decision confirmed the depths of the deposition tunnels in order to allow their use as initial data for the safety analyses required for the operating licence documentation; in connection with this, the ONKALO® vehicle connection routes were confirmed. This project-guiding decision does not af-fect the final disposal concept.
2. Excluding exhaust air shaft 2 from the plans. This project-guiding decision does not affect the final disposal concept.
3. Opening the ONKALO inlet air shaft. This project-guiding decision does not affect the final disposal concept.
4. Canister lid welding method. This project-guiding decision changed the lid welding method to be friction stir welding instead of the electron-beam welding presented in the construction licence application. The change was made during the processing of the construction licence application and documentation was submitted to STUK.

STUK found that changing the lid closure method does not have detrimental effects on safety. According to Posiva's own assessment, the change of the welding method improves the long-term safety of the canister weld, as friction stir welding results in fewer copper grain size changes that could, over a very long period, cause stress corrosion in the welding seam. This project-guiding decision has an effect that improves the long-term safety of the final disposal concept.

The following project-guiding changes were made after receiving the construction licence. These changes have been introduced into Posiva's plant and concept design under STUK's supervision and approval:

5. Change of implementation scope. This project-guiding decision specified the scope of implementing the disposal facility premises before the start of the final disposal at the so-called preparatory stage. This project-guiding decision does not affect the final disposal concept.

6. Selection of the transport container structure type. This project-guiding decision specified the transport container structure type. This project-guiding decision does not affect the final disposal concept.

7. Location of spent fuel verification measurement. This project-guiding decision specified where the spent fuel to be placed in final disposal is verified. This project-guiding decision does not affect the final disposal concept.

8. Processing and final disposal of encapsulation waste. This project-guiding decision specified how and where the low and intermediate-level nuclear waste generated at the encapsulation plant and disposal facility is processed and stored. This project-guiding decision does not affect the final disposal concept.

9. Change of implementation area for the first deposition tunnels. This project-guiding decision specified where the first deposition tunnels are built. This project-guiding decision does not affect the final disposal concept.

10. Number of canisters for the operating licence application. This project-guiding decision specified the exact number of final disposal canisters used in the analyses for the operating licence documentation. This project-guiding decision does not affect the final disposal concept.

11. Change of reference material in central tunnel backfill. This project-guiding decision changed the central tunnel backfill material. The central tunnels have no safety functions, so this change does not compromise long-term safety. This project-guiding decision does not affect the final disposal concept.

12. Buffer segmentation. This project-guiding decision changed the structure of the buffers installed in the deposition holes from circular blocks to segmented buffer blocks. This project-guiding decision does not affect the final disposal concept.

13. Increase of the degree of availability. This project-guiding decision changed the preliminary assumption for how much of the bedrock is available for final disposal. Posiva's more detailed research data on the Olkiluoto bedrock provided background information for this decision. This project-guiding decision does not affect the final disposal concept.

14. Change of deposition tunnel interval. This project-guiding decision changed the distance requirements for deposition tunnels and deposition holes based on more detailed calculations on residual heat generation. This project-guiding decision does not affect the final disposal concept.

15. Use of GraFi material as a deposition tunnel backfill material. This project-guiding decision changed the deposition tunnel backfill solution from a block-and-pellet backfill to a granule backfill solution. The granule backfill material is made from pellets by crushing and mixing. The material is installed into the tunnel by using separately designed installation equipment. This project-guiding decision does not affect the final disposal concept.

16. Size of the OL1-2 deposition tunnel. This project-guiding decision changed the size

of the deposition tunnels; the decision confirmed the size of the first deposition tunnels in order to allow for designing the equipment operating in the tunnels, among other things. This project-guiding decision does not affect the final disposal concept.

SUMMARY

Posiva has assessed the changes presented above through its own change management process, and the changes have been approved to be part of the final disposal concept. The design documentation of any changes that are significant in terms of safety are also subject to STUK's approval, and the installation and implementation are carried out under STUK's supervision. Final disposal operations will be carried out for approximately one hundred years; changes will be made as a result of technological advancements, but since Posiva has in place a controlled change management process, all the changes will be evaluated considering the different safety aspects. Any possible changes made in the future ensure safe and effective final disposal, and these changes too will be implemented under STUK's supervision.

14

REPORT ON HOW THE APPLICANT HAS ADHERED TO THE CONDITIONS OF THE CONSTRUCTION LICENCE

Photo: Posiva Oy

REPORT ON MEETING THE CONDITIONS OF THE OPERATING LICENCE

The following presents a report on the adherence to the conditions of the construction licence for Posiva Oy's encapsulation plant and disposal facility for spent nuclear fuel that was granted on 12 November 2015. The wording of the licence conditions is consistent with the operating licence, and they are written in italics below.

Licence conditions

> *The Government has, by virtue of the Nuclear Energy Act (990/1987) issued on 11 De-cember 1987 and the Nuclear Energy Decree (161/1988) issued on 12 February 1988, decided to grant, on the conditions stated below, Posiva Oy a licence referred to in Section 18 of the Nuclear Energy Act for the construction, at Olkiluoto in the municipality of Eurajoki, of an encapsulation plant and disposal facility for spent nuclear fuel generated in Finland and a disposal repository for the operating waste and decommissioning waste generated by the operation of the above facility, the main features and safety-related solutions of which correspond to what is presented in the construction licence application.*
>
> *This licence will expire if the construction of the encapsulation plant or disposal facility is not started within two years of the date when the licence becomes legally valid.*

The licence condition is met. The Ministry of Economic Affairs and Employment (TEM) received on 14 December 2016 a statement by the Radiation and Nuclear Safety Authority (STUK) which found that Posiva has started the construction of a disposal facility in Eurajoki. At the end of November 2016, STUK found that Posiva has achieved the readiness to begin the construction of a disposal facility according to Section 108 of the Nuclear Energy Decree.

Then, TEM assessed the condition set for the validity of the construction licence and the report that Posiva had started the construction and found that the condition was met.

> *1. With the licence granted by virtue of this decision, the licensee is allowed to construct*
>
> *1.1 an encapsulation plant and disposal facility for spent nuclear fuel, the total amount of which shall correspond to no more than 6,500 tonnes of uranium.*

The licence condition is met. According to the current plans, the final disposal of spent nuclear fuel will continue until the 2120s and, accordingly, the total amount of spent nuclear fuel placed in final disposal will be an amount equivalent to 6,500 tonnes of uranium. With this operating licence application, Posiva is applying for an operating licence for the final disposal of an amount equivalent to 6,500 tonnes of uranium.

> *1.2 disposal repository facilities for the low and intermediate level operation and decommissioning waste from the encapsulation plant and disposal facility. Disposal repository facilities may be constructed to an extent where the rooms may contain a maximum of 1,500 m3 of low and intermediate level waste.*

The licence condition is met. Posiva assigns the requirement to manage its low and intermediate-level waste to Teollisuuden Voima Oyj (TVO), which operates in the same Olkiluoto nuclear facility area. The nuclear facility waste generated at Posiva's nuclear facilities will be processed, stored and placed in final disposal according to the operating licences and permits of the Olkiluoto nuclear facilities. In the application, Posiva is applying for a disposal repository size of 3,000 m^3, as it is planned that the repository will also be used for the disposal of Posiva's nuclear waste if necessary.

After electricity production at Olkiluoto ends, the activities relating to the final disposal of spent nuclear fuel will continue and, therefore, the need may arise for Posiva to construct a separate disposal repository for low and intermediate-level waste. Therefore, in the operating licence application, Posiva is applying for a permit for a disposal repository for low and intermediate-level waste to be constructed in connection with ONKALO®.

1.3 the structures and auxiliary facilities required for the operation of the encapsulation plant and disposal facility and the disposal repository

The licence condition is met. Posiva will expand the disposal facility premises as final disposal progresses and construct the necessary structures and auxiliary facilities that enable the operation of the disposal facility. In its operating licence application, Posiva has also taken into account the construction of auxiliary facilities and structures.

1.4 the basic solution (vertical disposal tunnels) or a variation thereof (horizontal disposal tunnels).

The licence condition is met. According to Posiva's current plans, vertical deposition holes will be used for final disposal (the KBS-3V concept). Should the horizontal disposal concept (KBS-3H) prove to be a better way for the final disposal of spent nuclear fuel, the final disposal method can be changed. However, this would require extensive safety analyses and feasibility assessments. Posiva is applying for an operating licence for final disposal based on vertical deposition holes. However, Posiva will also retain the possibility of transitioning to horizontal final disposal, if necessary.

2. Together with the operating licence application, the licensee shall submit an updated analysis of the environmental impacts of the plant complex.

3. Together with the operating licence application, the licensee shall submit an updated analysis of the retrievability of the spent nuclear fuel.

4. Together with the operating licence application, the licensee shall submit an updated analysis of the risks related to the transport of spent nuclear fuel.

5. Together with the operating licence application, the licensee shall submit an analysis of the changes that have been introduced into the project.

The licence conditions are met. Posiva has enclosed the updated analyses pertaining to licence conditions 2 to 5 as appendices 10 to 13 to this operating licence application.

Posiva

Posiva Oy is the global leader in final disposal, and it is preparing to start the final disposal of spent nuclear fuel in the ONKALO® facility, excavated deep in the bedrock, in the 2020s.