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Monitoring of radioactivity in the environment of Finnish nuclear power plants

Annual report 2022

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KEY WORDS: Environmental monitoring, nuclear facility

Contents

1 Summary

This report describes the results of radiation monitoring carried out by the Radiation and Nuclear Safety Authority (STUK) in the environment of the Loviisa and Olkiluoto nuclear power plants in 2022. STUK's monitoring activities complement and verify the environmental monitoring and release measurements conducted by the power plants. The monitoring is implemented by collecting samples from the land and marine environment in the vicinity of the power plants and of outdoor air. In addition, the concentrations of radioactive substances in the bodies of inhabitants of the surrounding area of the power plant are monitored. The environmental samples are analysed in STUK's laboratory. The radioactive substances contained in the collected samples are determined by gamma spectrometric and radiochemical analysis methods.

In some of the collected samples, small quantities of radioactive substances originating from the power plant were found. There was no significant deviation from the environmental findings of the previous years in terms of the identified radioactive substances or their quantities. Radioactivity originating from the power plant observed in the environment is insignificant in terms of radiation exposure of the environment and people. The results of the release measurements reported by the nuclear power plants and the findings of the environmental monitoring carried out by the nuclear power plants correspond to the findings made by STUK as part of its own monitoring.

2 Introduction

The use of nuclear energy is prescribed for in the Nuclear Energy Act (990/1987) and Nuclear Energy Decree (161/1988). Under Section 7 c(1) of the Nuclear Energy Act, *releases of radioactive substances caused by the use of nuclear energy shall be restricted in compliance with the optimisation principle of radiation protection laid down in Section 6 of the Radiation Act (859/2018). In the optimisation of radiation protection, dose constraints in accordance with Section 9 of the Radiation Act shall be used.* Under section 7 c(5) of the Nuclear Energy Act, *the Radiation and Nuclear Safety Authority shall, to the extent necessary, monitor and oversee the environment of a nuclear facility to verify the reliability of measurements of radioactive releases and to ascertain the environmental impact of the facility.* Environmental radiation monitoring ensures for its own part that the annual dose of an individual in the population, arising from the normal operation of a nuclear power plant, stays below the annual dose constraint of 0.1 millisievert as regulated in Section 22 b of the Nuclear Decree (161/1988). The annual dose constraint is less than 2% of the average annual dose of Finnish people of 5.9 mSv (Siiskonen, 2020).

Radiation exposure arising from the operation of a nuclear power plant shall be kept as low as reasonably achievable. A nuclear facility and its operation shall also be designed so that the constraints presented in the Nuclear Energy Decree are not exceeded. It is not sufficient to stay within the constraints; the releases of radioactive substances and environmental radiation levels resulting from the operation of a nuclear facility shall be kept as low as possible. The holder of a licence entitling them to the use of nuclear energy shall derive the release limits of radioactive substances for the nuclear power plant in such a way that the constraint on the individual dose under the Nuclear Energy Decree is not exceeded.

STUK's Guide YVL C.7 gives the detailed requirements applicable to the licensee for the radiological monitoring of the environment of a nuclear facility.[1] The licensee shall draw up a programme for the radiation monitoring of the environment of the nuclear facility and report the results of the programme to STUK. According to Guide YVL C.7, STUK shall perform independent regulatory control in the environment of the nuclear facility during the operation of the nuclear facility by collecting and analysing samples from the surroundings of the nuclear facility to a necessary extent. With regard to arranging the environmental monitoring of nuclear facilities, the IAEA has also issued a guide Environmental and Source Monitoring for Purposes of Radiation Protection, IAEA Safety Standards Series No. RS-G-1.8 (IAEA, 2005). The entity formed by the environmental monitoring conducted by the licensee and STUK is in line with the recommendations regarding the contents of the IAEA's monitoring programme.

The results of environmental monitoring conducted by STUK are compiled to this report. The results are compared against the environmental monitoring findings and releases reported by the licensees.

3 Releases from nuclear power plants

During the normal operation of nuclear power plants, radioactive substances are generated, a very small proportion of which may end up in the environment. Radioactive substances are mostly generated to the reactor's nuclear fuel as a result of nuclear fission and as activation products of various materials as a result of neutron radiation. Radioactive substances remain mostly inside the fuel rods as the rod cladding prevents the release of the substances into the surrounding cooling water. The reactor cooling system and related cleaning and waste systems also contain radioactive substances. Gaseous radioactive substances are also generated in the fuel which can, by diffusion, leave the fuel rods. In rare cases, the fuel rod cladding can get damaged in use and lose its tightness, increasing the radioactivity of cooling water.

During the normal operating conditions, the nuclear facility releases into the atmosphere the facility's ventilation exhaust air and the gaseous substances removed from the processes, which have been purified, if necessary. Gaseous releases are directed to the power plants' exhaust air system. Liquid radioactive substances generated at the nuclear power plant are reduced by evaporation, filtration and delay before they are discharged into the sea. Releases of liquid radioactive substances are discharged with the power plant's cooling water into the sea. In disturbance and accident situations, radioactive substances can be released into the environment also via abnormal routes and the composition of the releases may differ from the releases of normal operation.

In December 2021, the surface water of the Cs separated evaporation concentrate tanks was discharged at the liquid waste storage of the Loviisa power plant. This discharge is carried out approximately once every four years. Cs separation was started in the 1990s and it has been able to clearly reduce liquid discharges to the environment. As a result of the discharge, radioactive releases into the sea were higher than they have been in the years

[1] The licence holder shall refer in this report to the holder of a licence providing entitlement to the use of nuclear energy.

when the discharge has not been made. The impact of the discharge was seen in the environmental samples, as the activity concentrations of Co-60 and Ag-110m were slightly higher in the winter collection of sinking matter and periphyton.

Similarly, to previous years, the 2022 releases were considerably below the set release limits.

At Olkiluoto, the OL3 plant unit reached its first criticality on 21 December 2021. In 2022, the commissioning of the plant unit proceeded within the safety objectives and the plant was operated at 100% of capacity for the first time on 30 September 2022. Regular electricity production started on 16 April 2023.

In 2022, the radioactive discharges from the power plants were small in relation to the set release limits (Fortum, 2023; TVO, 2023). In Loviisa, the release of noble gases into the atmosphere (Kr-87 equivalent release) was approximately 0.04% and the release of iodine (I-131 equivalent release) was approximately 0.00001% of their respective release limits in 2022. The release of tritium (H-3) into the sea was approximately 10% and the release of fission and activation products into the sea was approximately 0.008% of their respective release limits.

At Olkiluoto, the release of noble gases into the atmosphere was 0.0106% and the release of iodine (at Olkiluoto, the release limit was set for I-131) was 0.0744% of their respective release limits. The release of tritium into the sea was approximately 2.85% and the release of fission and activation products into the sea was approximately 0.0404 % of their respective release limits.

Typical radionuclides originating from the Loviisa power plant and found in the vicinity of the power plant are H-3, Co-60 and Ag-110m and those of the Olkiluoto power plant are H-3, Mn-54, Co-58 and Co-60. The differences in the observed nuclides are due to the different plant types and differences in the materials used in the reactor circuits, for example.

The nuclides causing the largest calculated dose for an individual in the most highly exposed population group are C-14 for air releases and Co-60 or Cs-137 for water releases. The calculated dose estimate for the part of Loviisa C-14 atmospheric releases is based on the conservative assumption that C-14 is fully released into the environment as carbon dioxide (CO_2). However, studies show that 80–90% of C-14 releases are released as hydrocarbons that are not easily absorbed by plants (Fortum 2022). For this reason, the samples collected by the environmental monitoring from the surroundings of the nuclear power plants show very little difference to the C-14 activity concentrations of samples collected from elsewhere in Finland. For this same reason, the calculated dose estimate of an individual in the most highly exposed population group in Loviisa is probably also estimated to be higher than it actually is for the part of C-14.

Annex 1 presents in more detail the most common radionuclides detected in releases from the nuclear power plants and in environmental monitoring. Not all radionuclides detected in environmental monitoring originate from the nuclear power plants. There is also natural radioactivity and artificial radionuclides in the environment, such as H-3, Sr-90 and Cs-137, originating from the nuclear weapons testing of the 1950s and 1960s and, in particular, from the Chernobyl disaster of 1986.

4 Environmental monitoring programme of the licensee

The holder of a licence authorising the use of nuclear energy shall monitor the concentrations of radioactive substances in the environment of the power plant. Guide YVL C.7, published by STUK, provides the minimum requirements for the licensee's environmental radiation monitoring programme (Annex 2):

- The programme shall include external radiation measurements carried out using environmental dosimeters located in the plant's terrestrial environment and external radiation dose rate measuring stations.
- In the terrestrial environment, the measurements shall be focused on the definition of radioactive substances in the air, atmospheric deposition, domestic water and garden products. In addition, the monitoring programme shall examine the radioactive substances in the indicator organisms in the terrestrial environment. Indicator organisms refer to organisms and plants that collect or enrich radionuclides particularly well and are therefore suitable for the monitoring of radionuclides in the environment.
- In the water environment, the measurements shall be focused on the definition of radioactive substances diluted and mixed in the water.

The results of the environmental radiation monitoring of the licensee are presented in the licensee's annual report for environmental radiation safety, which the licensee submits to STUK (Fortum, 2023; TVO, 2023). STUK assesses the adequacy of the licensee's own monitoring programme and its results and compares the results of the licensee's monitoring with those of STUK's own monitoring programme. The results of the licensee's programme are covered later in Section 6, Results of environmental monitoring, where the results are compared to the results of STUK's monitoring programme.

5 Environmental monitoring programme and methods of the Radiation and Nuclear Safety Authority

STUK's environmental radiation monitoring programme is designed to take into account the conditions of the plant sites and their surroundings and the operation and use of the plants. In this way, the radiation monitoring of the environment is carried out correctly targeted and dimensioned. In addition to the planned programme, additional sampling may be carried out if necessary, for example in the event of plant transients. Environmental radiation monitoring is targeted at the plant environment and the surrounding population. The quality of sampling is ensured by annually taking replicates of certain sample types in accordance with the plan.

Measurements are made on the terrestrial and marine environment samples, in addition to which air samples are collected during the annual outages of the plants. Sampling focuses primarily on food chain-related sample types, such as milk, agricultural products, domestic water, fish, game and other food. In addition, the radiation monitoring programme includes indicator organisms and materials of the aquatic and terrestrial environment, such as wild terrestrial and marine environment flora and sinking matter.

The same or similar sample types are collected from the environment of both nuclear power plants, taking into account local conditions. The sampling items and types are selected so that they reflect as well as possible the state of the immediate surroundings of the plants. Samples are taken representatively up to a distance of several kilometres from the plant, taking into account any release routes of radionuclides, the dispersion of releases into the environment, the habits of the population and the location of settlement in the environment. The radionuclide concentrations of the samples are compared against the radionuclide concentrations of samples collected elsewhere in Finland and with the observations of previous years.

5.1 Monitored pathways and sampling

The sample types are divided into three main groups: air and terrestrial and marine environment samples. In addition to these, the accumulation of radioactive substances in the inhabitants in the vicinity of the power plant is studied. Sampling of the environmental samples according to the monitoring programme is usually carried out by STUK's sampler. Some samples under the monitoring programme are obtained directly from local farmers, growers or other operators. The sampling schedule is presented in Annex 3.

In 2021, quality assurance sampling was also included in the programme. Parallel samples shall be collected annually from one marine environment and one terrestrial environment target. In 2022, the sample types were sinking matter and lingonberry.

5.1.1 Outdoor air and atmospheric deposition

Continuous collection of outdoor air samples is part of the licensee's monitoring programme. STUK collects outdoor air particle samples supplementing the licensee's measurements during the annual outages of the plants. STUK's supplementary air sample collector (Figure 1) is equipped with fibreglass filters. The air samplers of the licensees also use active carbon cartridges (TVO) or carbon impregnated fibreglass filters (Fortum). The fibreglass filter collects aerosols, which are solid or liquid particles floating in the air. Typical aerosol particles are of a micrometre size. The activated carbon cartridge collects gaseous substances, such as radioactive iodine. The air sampler flow meters measure the air volumes passing through the fibreglass filter and the carbon cartridge. The accumulated radioactivity in the filter and carbon cartridge is calculated in Bq/m^3 in proportion to the volume of air pumped through the filter.

The licensees' programme determines gamma-active radionuclides from the atmospheric deposition samples. In addition to these, STUK examines the activity concentration of Sr-90 from the whole year's composite atmospheric deposition samples collected by the licensees as part of STUK's monitoring programme.

Figure 1. Mobile air sample collector.

5.1.2 Terrestrial environment

The terrestrial environment samples include soil, reindeer lichen, haircap moss, needles, ferns, mushrooms, berries, game, milk samples, grazing grass, crops, root vegetables, domestic water, groundwater and sludge.

Monitoring of soil radioactivity is carried out as a survey every two years. Samples are collected from the surface layer of soil. Radionuclides can get carried via atmospheric releases of the power plants to surface soil. Surface soil radionuclides can increase the exposure of humans to radioactivity directly by increasing the external radiation dose or indirectly through food. Terrestrial samples are taken from 3–5 locations in the surroundings of both power plants every two years. The samples are taken at a depth of 0–5 cm, for example with a golf hole cutter (Figure 2) and 3–5 primary samples are taken from the same depth to be combined into a single sample. Where appropriate, samples may also be taken to examine the depth profile of radionuclides. A flat, open and intact area with as few stones and roots as possible is selected as the sampling area.

Species of wild plants identified as good enrichers of radioactive substances, such as haircap moss, reindeer lichen, ferns (common polypody and ostrich fern) and spruce needles (new annual growth), are collected once a year. Since 2021, haircap moss has been replaced with another fern sample in Loviisa. The plants are dried and ground. Reindeer lichen is picked from an area where there are as few other species and organic debris as possible. In addition to the neighbouring areas of the power plants, reference samples of each species are collected from elsewhere in Finland. Samples of berries and four different species of mushroom are also collected annually from the vicinity of the power plants according to local availability. Efforts are being made to obtain samples of game meat from local hunters for examination.

By examining agricultural products and domestic water, it is possible to assess the exposure of humans to radioactive substances via food. Milk samples from nearby dairies are collected by the dairies in containers supplied and labelled by STUK. The milk comes from dairy farms in the vicinity of the power plants, the longest distances from the power plant being about 40 km. Sampling observes the general procedures for the food sampling of milk. Grazing grass samples are collected from the vicinity of the power plant once during the growing season. The aim has been to select pastures so that the milk from the cows grazing on them goes to the same dairies from where the milk samples of the monitoring programme are collected. The analysis of garden and agricultural products includes different cereals and root vegetables. Crop samples are obtained from local farmers at grain farms located in the environment of the power plants extending to a distance of approximately 20 km. Samples are taken from two varieties of cereal once a year after harvest. One root vegetable sample (potato, carrot, swede) is obtained from local producers in the vicinity of the power plants once during the summer season.

Domestic water samples are collected from the domestic water of the cities of Loviisa and Rauma twice a year, in the spring and autumn. As part of STUK's monitoring programme, Sr-90 is also determined from domestic water samples taken at the power plant, which are covered by the licensees' programme. The groundwater sample is collected from a well producing groundwater near the power plants or directly from the groundwater pipeline. Sludge samples are collected before or after and once during the annual outage from the water treatment plants of the neighbouring cities. The sampling sites for the terrestrial environment are shown in Figures 3 and 4.

Figure 2. Slicing of a soil sample taken with a golf hole cutter.

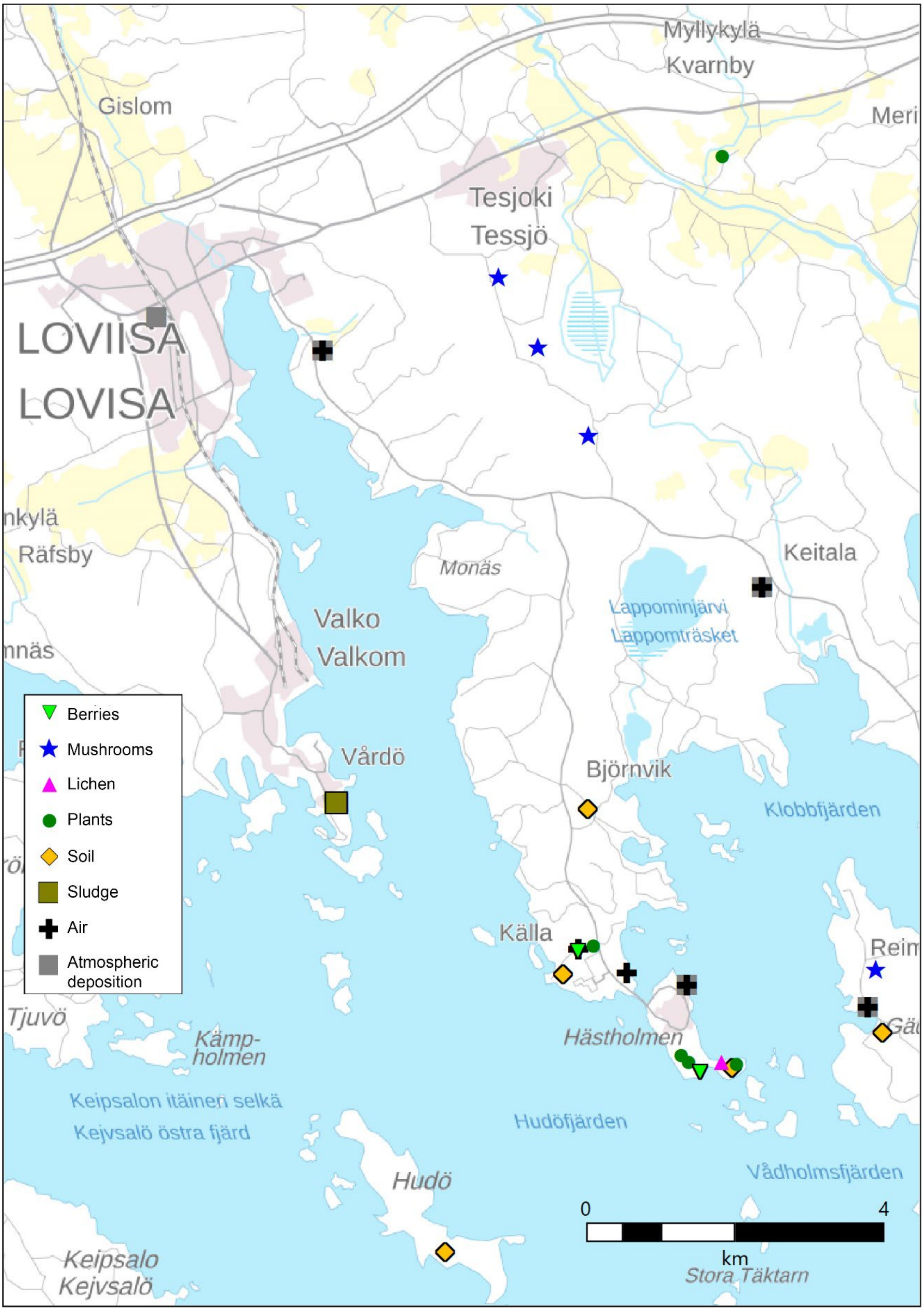

Figure 3. Sampling sites in the terrestrial environment of Loviisa. The map includes data from the Background map series of the National Land Survey of Finland.

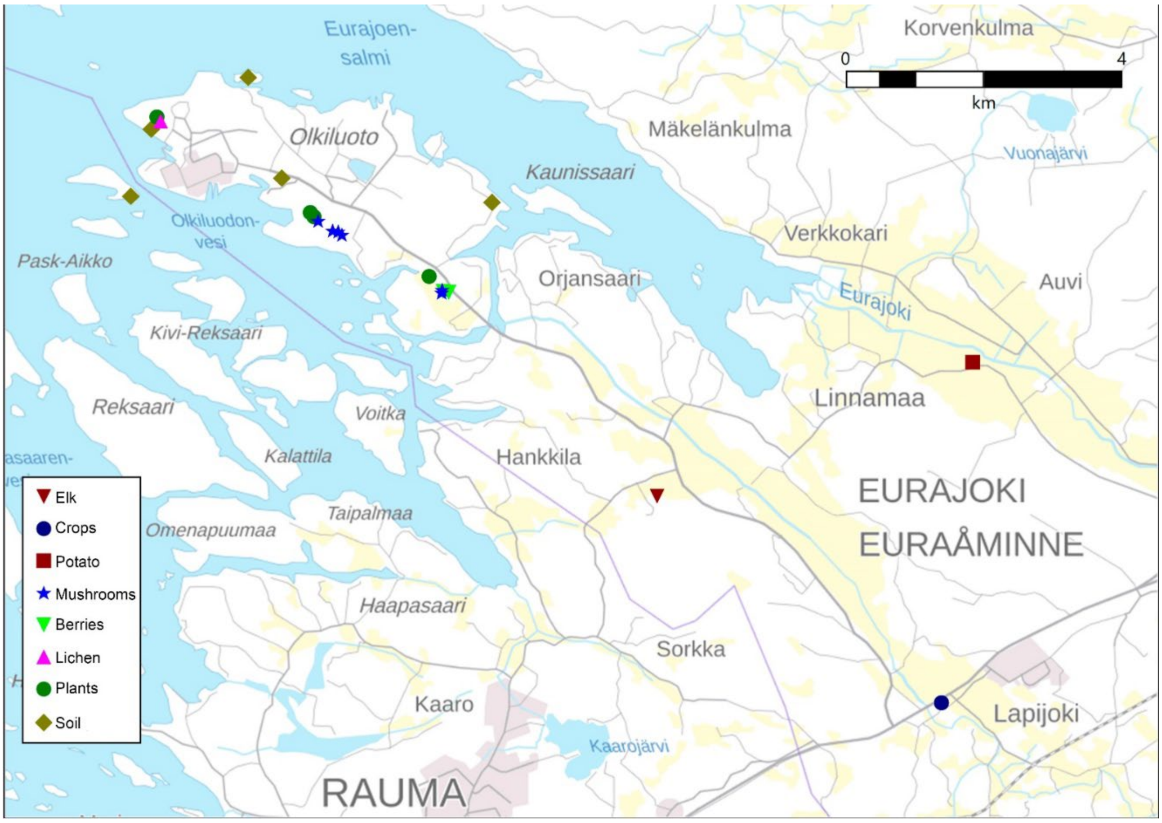

Figure 4. Sampling sites in the terrestrial environment of Olkiluoto. The map includes data from the Background map series of the National Land Survey of Finland.

5.1.3 Marine environment

Marine samples help to monitor the dispersion of power plant releases in the marine environment and their accumulation in marine environment flora and fauna. Seawater, periphyton, bladder wrack, aquatic plants with submerged leaves (spiked water milfoil), bottom fauna, fish, bottom sediment and sinking matter are collected from the marine environment. The sampling sites for the marine environment are shown in Figures 5 and 6.

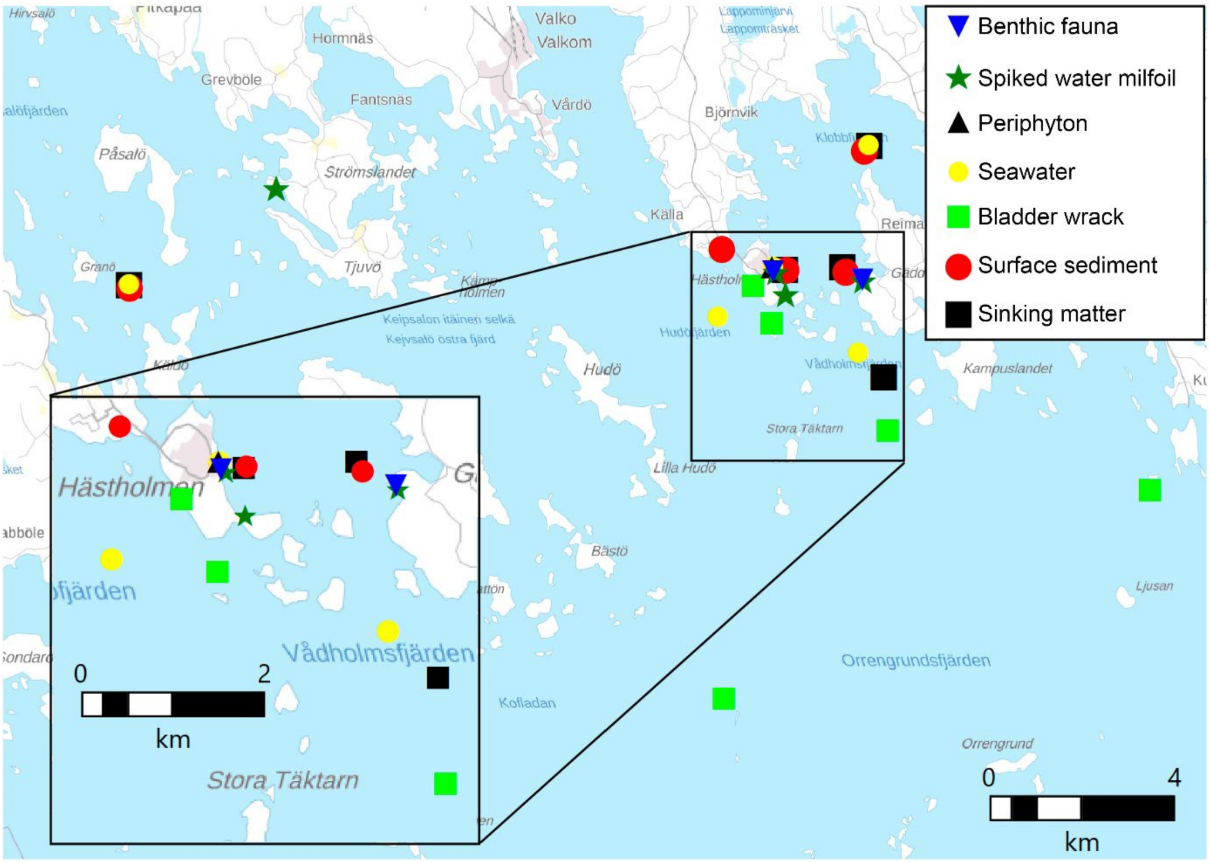

Figure 5. Sampling sites in the marine environment of Loviisa. The map includes data from the Background map series 04/2020 of the National Land Survey of Finland.

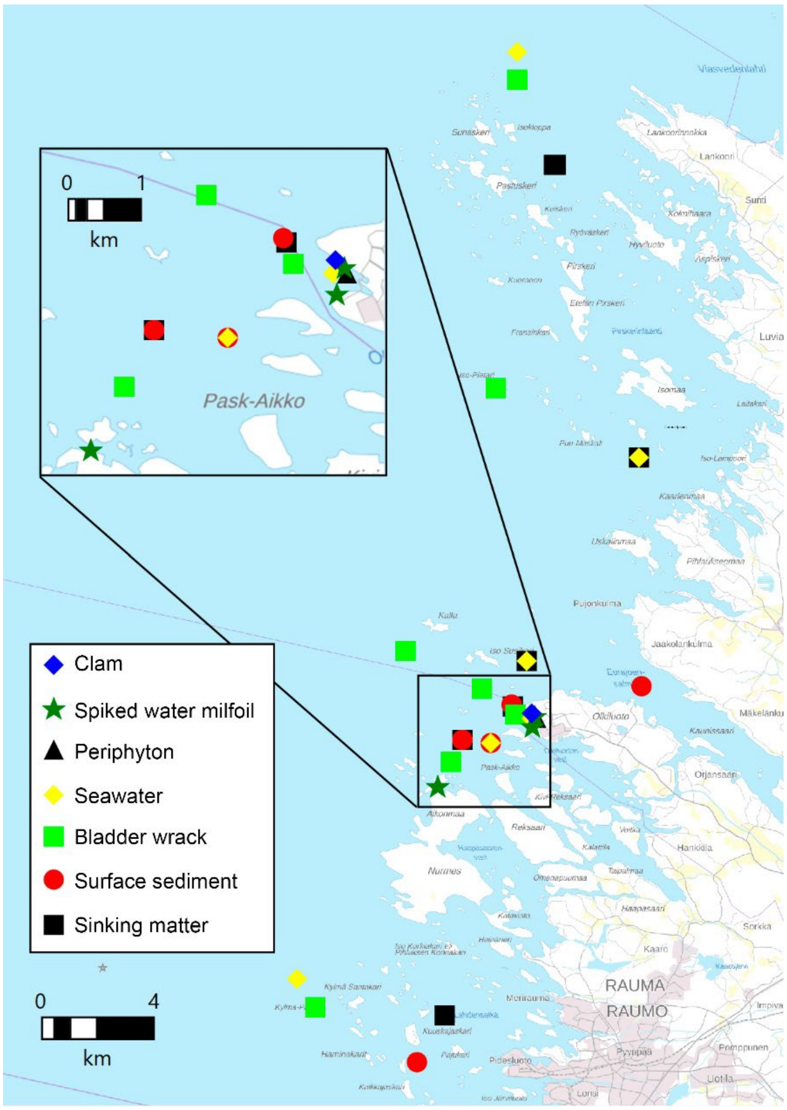

Figure 6. Sampling sites in the marine environment of Olkiluoto. The map includes data from the Background map series 03/2021 of the National Land Survey of Finland.

Seawater samples (surface water) are collected from several sampling points in the environment of the power plants. The point closest to the nuclear facility is sampled more frequently and the others less frequently.

The examination of aquatic plants includes bladder wrack and spiked water milfoil. These plants efficiently collect radionuclides from water and are therefore good release indicators. Bladder wrack samples are taken at several points several times a year (Figures 7). Plants are collected both in the areas where the cooling water is discharged and further away from the power plant. Especially in Loviisa, general changes in environmental conditions (e.g. eutrophication of waters) are reflected in a deterioration of the bladder wrack population near the power plant. Also periphyton is collected as algal samples. Periphyton refers to organisms attached to a solid surface in water, mainly algae. Periphyton is collected onto a 50 x 50 cm polycarbonate plate throughout the growing season (May–November). In Loviisa, periphyton has also been collected throughout the winter season (November–April). Factors affecting the growth of periphyton include flow rate, light and water quality.

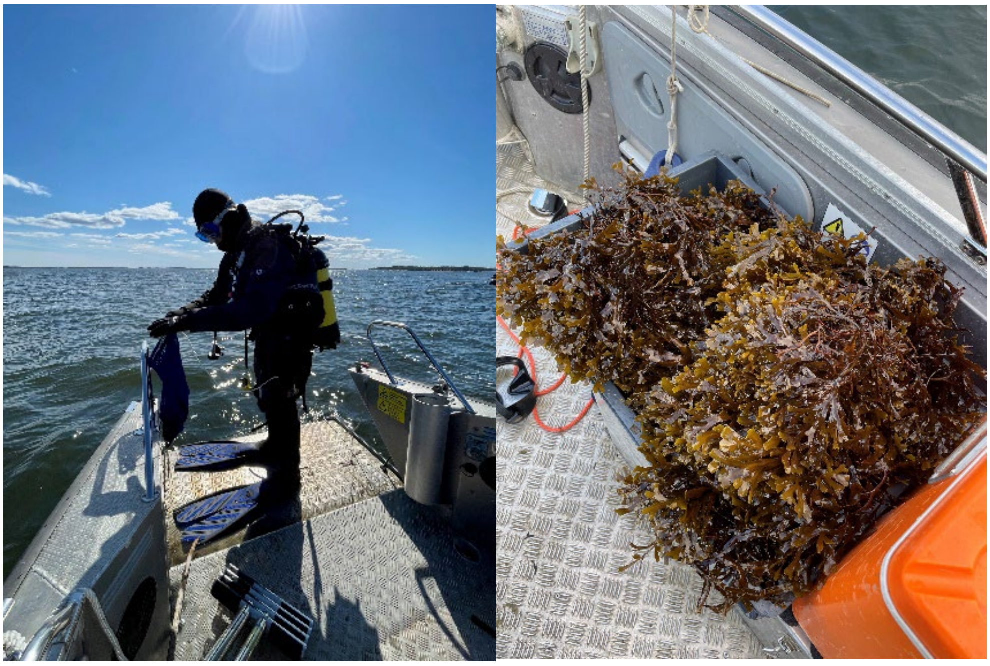

Figure 7. Sampling of bladder wrack by means of scuba diving. Bladder wrack (on the right).

The benthic fauna sample type includes blue mussel or *Mesidothea entomon*, depending on availability. In 2022, the catching of *Mesidothea entomon* in Loviisa failed to start until the waters had already warmed considerably, and the necessary amount was not caught during the summer. Gulf wedge clam (*Rangia cuneata*), which has appeared as an invasive species in the area, was chosen as a replacement sample. Blue mussel could not be found from the Iso Kaalonperä sampling point in Olkiluoto. Also in this case, the alien gulf wedge clam was collected as a replacement sample. The samples are collected from one sampling point once a year (Figure 8). Fishing for fish samples is done once a year in May–October and the number of sample species must be at least four every year: for example, Baltic herring, pike, perch and bream. As regards Loviisa, a fry sample received from a nearby fish farm is also examined. There is no fry farming activity near Olkiluoto. If necessary, a sample of Baltic herring suitable for analysis may be obtained from a local fish wholesaler, provided that the normal sampling fishing does not yield catch. In addition, a comparison sample of pike is taken, whose fishing area is not in the immediate vicinity of the power plants.

Sinking matter refers to particles that sink in water towards the bottom, consisting mainly of organic solids produced in the open sea area and in the shore zone, organic and inorganic solids brought by runoff water and river water and solid matter of bottom sediment getting occasionally mixed with water. Sinking matter is collected year-round from several sampling points into cylindrical collecting tubes, which are anchored to the desired depth (Figure 9). The bottom sediment samples are collected annually from 5–6 points and a surface layer of 0–5 cm is taken as a sample. The bottom sediment sample is taken with a dedicated cylindrical sediment collector with a steel structure (Gemini), which sinks into the sediment due to its own weight or additional weights and the closure mechanism locks the sediment plug inside the collector.

Figure 8. Gulf wedge clam (*Rangia cuneata*).

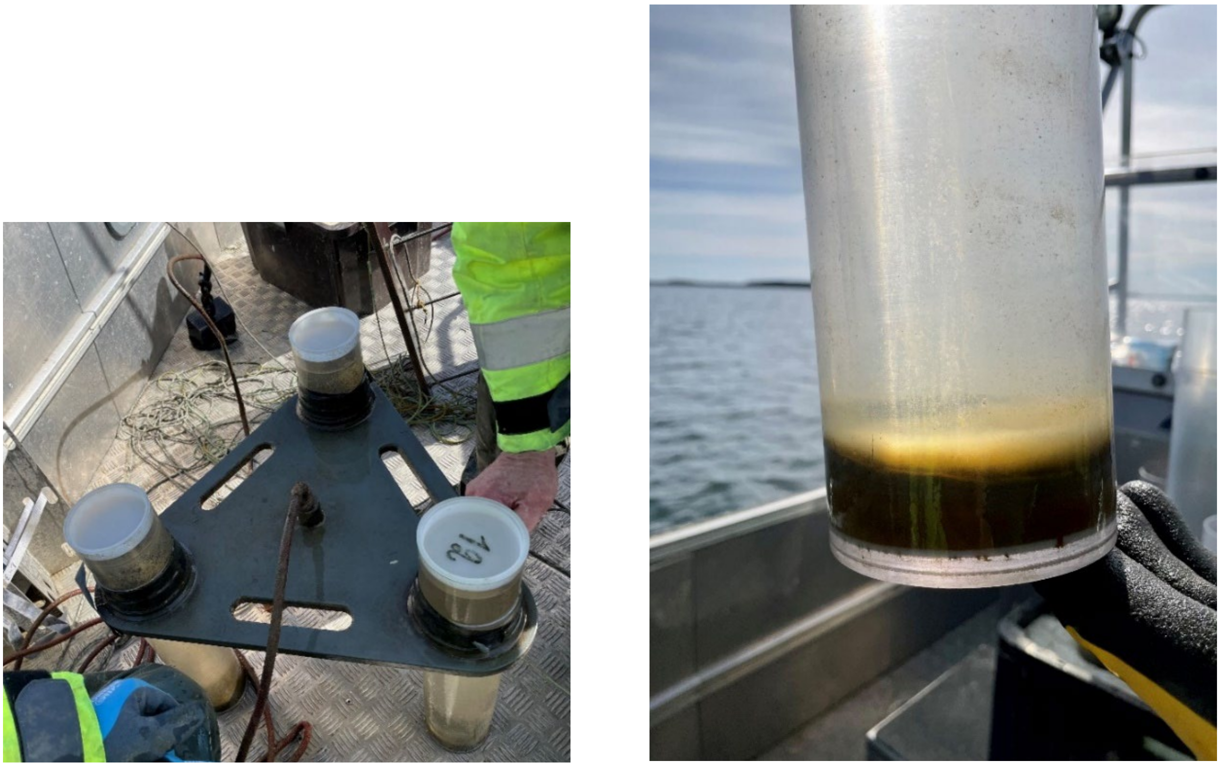

Figure 9. A collector of sinking matter and a collection tube at the end of the sampling period.

5.1.4 Inhabitants of the surroundings

Once a year, people living in the environment of the nuclear power plant are given the opportunity to participate in a measurement to determine the amount of radioactive substances accumulated in the human body. The aim is to get a minimum of 20 inhabitants in the vicinity of both power plants to take part in the measurement every year by sending them an invitation letter by post. The invitation is sent primarily to persons with a residential address within 7 km of the nuclear power plant in the year of arranging the measurement. The group of invited persons is supplemented by a sample of persons whose residential address is within 10 km of the nuclear power plant. The name and address data are based on the data in the Population Information Register of the Finnish Digital and Population Data Services Agency. Persons of age are invited to take part in the measurement. Participation in the measurement is voluntary and the measurement results are used in a form that does not allow the results to be associated with individuals or their residential addresses.

The gamma-radiating radionuclides contained in the body of the inhabitants of the surroundings of the nuclear power plant are determined by direct gamma-spectrometric measurement from outside the body. This so-called whole-body counting is carried out with special measuring equipment built on a truck. The measurement takes approximately 15 minutes and, during the measurement, the person sits on a chair inside a background radiation shield. During the measurement, the body is not subjected to radiation and no samples are taken from the subject. The measurements would show if the population in the vicinity had accumulated deviating quantities of radionuclides originating from the power plant. The person receives their measurement result immediately after the measurement.

5.2 Monitoring methods

Sampling and laboratory analyses under the monitoring programme are primarily carried out by the Measurements and Environmental Monitoring department of STUK. Milk, crop, root vegetable, fry, game and sludge samples come from external suppliers. The C-14 analyses of the monitoring programme are carried out at the Laboratory of Chronology of the University of Helsinki. The Measurements and Environmental Monitoring department of STUK is a testing laboratory T167 accredited by FINAS, accreditation requirement EN ISO/IEC 17025:2017.

5.2.1 Sample processing and analysis

The samples are sent to STUK's laboratory for analysis. If necessary, the samples are cleaned to only contain the studied sample type. Spoiled samples and samples otherwise not meeting the quality criteria are rejected in the pre-processing phase.

Food samples are processed so that the measurements are made from the edible parts. A preservative is added to milk samples to prevent contamination. The milk samples are evaporated under heat lamps and burnt. The iodine content (I-131) of milk is determined using a separate sample of about half a litre without pre-processing by means of direct gamma-spectrometric measurement. The samples to be dried (lichen, moss, needles, ferns, mushrooms, berries, game, grazing grass, crops, root vegetables, sludge, fish, benthic fauna, bladder wrack, periphyton, aquatic plants) are dried in a drying oven and, then, homogenised by grinding. Fresh and whole fry are measured. The sediment samples and the sinking matter are dried in a freeze dryer and homogenised by grinding. The soil samples are dried in a drying oven and sifted with a 2-mm sieve. Seawater samples are evaporated to a smaller volume by means of heat lamps. For the radiochemical analyses of strontium, the samples are burnt after a gamma-spectrometric measurement. For the determination of tritium, water samples are distilled. The results of food and environmental samples are reported per sample volume or dry weight (DW), except for the results of mushrooms, berries, root vegetables, game and fish, which are reported per fresh weight (FW). The activity concentrations of dried samples per unit of weight are significantly higher than those of fresh samples.

Radionuclides emitting gamma radiation are analysed from all samples, including Co-60, I-131, Cs-134 and Cs-137. Radionuclides emitting gamma radiation are identified by the energies of gamma radiation typical of each isotope.

Radiochemical methods are used to analyse the alpha- and beta-active substances (H-3, Sr-90 and Pu-238, Pu-239 and Pu-240) of the samples. The analyses of strontium's short-lived isotope Sr-89 were discontinued in 2021. Sr-89 can still be determined from samples, if another instance of environmental monitoring indicates an abnormal environmental emission. Data from previous years shows that the Sr-89 activity concentrations in environmental samples have remained below the specified limits.

In the radiochemical analysis, the chemical separation of the elemental to be examined is carried out first from the sample. In the determinations of strontium, stable Sr and Cs carrier is first added to the samples and the dry samples are liquefied. Strontium is separated from the sample by an extraction chromatography method and Sr-90 is measured from the sample with a liquid scintillation spectrometer. Strontium catch determination is done using an inductively coupled plasma-mass spectrometer (ICP-MS). H-3 is determined directly from the distilled water sample by means of a liquid scintillation spectrometer. For plutonium analyses, the Pu-242 tracer is added to the samples and the samples are liquefied before chemical isolation. Plutonium is separated from the other alpha-active radionuclides by ion exchange, and the measurement sample is prepared by precipitation and measured by alpha spectrometry. The resolution of an alpha spectrometer is not sufficient to distinguish plutonium isotopes Pu-239 and Pu-240 from each other, therefore the results indicate their combined activity concentration in the samples. C-14 is determined from dried samples at the Laboratory of Chronology of the University of Helsinki.

The radiochemical methods are cumbersome and time-consuming compared to the simple determination of nuclides emitting gamma radiation, therefore it is not possible to routinely determine the alpha- and beta-active radionuclides from each sample. Radiochemical analyses have been selected for sample types where they play a significant role in human radiation exposure (e.g. Sr-90 in milk and H-3 in domestic water) or where they may occur (e.g. H-3 in seawater and Pu-239 or Pu-240 in marine environment sediments). If the results of the monitoring programme were to indicate an increase in the activity concentrations of some alpha- or beta-active radionuclides in the samples, it is possible to increase the scope and frequency of the radiochemical analyses. The analyses to be carried out on the different sample types are shown in Table 1.

Measurement times of the samples vary according to the sample and may, in individual cases, be longer than usual, for example when a sample is left for measurement for the weekend. A longer measurement time may be the reason for the lower than average observation limit reported for some individual samples. In this case, smaller quantities of radioactive substances may also be detected in individual samples. The calculated activity concentrations of the radionuclides correspond to the average of the collection period, therefore the activity concentrations do not accurately reflect the activity concentrations of short-term releases that are temporarily higher. The uncertainty of the results is given to an accuracy of 2 σ (95% confidence interval).

Table 1. Monitored pathways and analysed radionuclides in STUK's monitoring programme.

Monitoring item	Gamma	Sr-90	C-14	H-3	Pu-238, Pu-239, Pu-240
Outdoor air	x				
Atmospheric deposition (annual sample)		x			
Soil	x	x			
Reindeer lichen	x				
Haircap moss	x				
Needles	x		x		
Ferns	x	x			
Mushrooms	x				
Berries	x				
Game	x				
Milk	x	x			
Grazing grass	x		x		
Crops	x	x			
Root vegetable	x				
Domestic water	x	x		x	
Groundwater	x				
Sludge	x				
Seawater	x	x		x	
Fry	x				
Periphyton	x				
Bladder wrack	x	x			x
Spiked water milfoil	x				
Benthic fauna	x	x			
Fish	x	x			
Surface sediment	x	x			x
Sinking matter	x				
Inhabitants of the surroundings	x				

6 Results of environmental monitoring

Approximately 460 samples were collected and analysed in the terrestrial and marine environment of the Olkiluoto power plant during 2022. Approximately 140 of the samples were STUK's monitoring samples and the rest were part of the licensee's own monitoring programme. Approximately 450 samples of the terrestrial and marine environment of the Loviisa power plant were examined during 2022. Of these, 125 were STUK's regulatory oversight samples. In addition to these, the radioactivity accumulated in the bodies of the inhabitants in the surrounding area of both power plants was measured.

The detailed analysis results of STUK's control measurements of the 2022 samples are given in Tables 2–24. The results of the licensees' own measurements are discussed in the text. Not all radionuclides present in the result tables originate from the Olkiluoto or Loviisa power plants. There is always radioactive isotope of potassium K-40 in the environmental samples and in human beings, usually forming the majority of the natural radioactivity of the samples. The terrestrial environment samples also contain Be-7, which is produced in the upper atmosphere due to cosmic radiation. Almost all samples contain a small amount of radionuclide Cs-137, originating from the nuclear weapon tests conducted in the atmosphere and from the Chernobyl disaster. In addition to K-40, this old Cs-137 forms a part of the background concentration observed in the environmental samples. The typical background concentration of Cs-137 in outdoor air in Finland is around 1–4 μBq/m^3 and the Cs-137 atmospheric deposition in the Helsinki area is typically less than 0.5 Bq/m^2 per month (Mattila and Inkinen, 2022). In the Gulf of Bothnia and the Gulf of Finland, the concentration of Cs-137 in seawater is usually around 20–30 Bq/m^3 and the concentration of Sr-90 around 4–11 Bq/m^3 (HELCOM, 2018). The Cs-137 background concentration in the terrestrial and marine environment can vary strongly according to geographical location, as has been observed, for example, in the activity concentrations of Cs-137 in the Baltic Sea sediments (HELCOM, 2018). If the monitoring samples were to show Cs-137 originating from the power plant, this could be observed in elevated concentrations compared to the regional background concentration and observations from previous years and in the appearance of another radionuclide Cs-134, with a shorter life, in the environmental samples.

6.1 Outdoor air and atmospheric deposition

Continuous monitoring of radioactive substances in outdoor air is the responsibility of the licensee. STUK carries out outdoor air sampling supplementing the licensee's measurements in conjunction with the annual outages at the plant sites (Table 2). The Cs-137 activity concentrations of the air samples were low. A small leak was detected in the primary circuit of unit 2 of the Loviisa power plant at the end of the outage period. For this reason, an additional air sample was taken in Loviisa, from which no artificial radionuclides were detected.

In the outdoor air samples collected by the licensee in Loviisa, it was possible to detect a small concentration of Co-60 in the samples collected in May–June at three collection stations and, in addition, Sc-46 at one of these three collection stations (Källa). No other radionuclides originating from the power plants were detected in the licensee's own outdoor air samples.

Table 2. An air sample supplementing the licensees' monitoring.

Collection site	Collection period	Co-60 μBq/m³	Cs-137 μBq/m³	Uncertainty 2σ
Loviisa	9.6.22	< 0.3	0.63	30%
	1.6.22	-	< 0.8	
Olkiluoto	6.6.22	< 0.4	0.64	24%

The collection and monitoring of atmospheric deposition samples also belong to the monitoring programme of the licensees. The licensee's programme determines gamma-active radionuclides from the atmospheric deposition samples, and Sr-90 is determined from the annual sample combined from these atmospheric deposition samples as part of STUK's monitoring programme. In Loviisa, the total surface activity of Cs-137 in the atmospheric deposition samples of the whole year varied between 0.3 and 1.2 Bq/m^2. After the nuclear weapons tests carried out in the atmosphere, there has been tritium in the atmosphere and this so-called background concentration has decayed through the years. Activity concentrations above 2 Bq/l can be considered as a finding of power plant origin. Tritium concentrations varied between 1.2 and 3.4 Bq/l or were below the specified limit. At Olkiluoto, the corresponding range was 0.9–1.5 Bq/m^2 for Cs-137 and 1.1–2.4 Bq/l or below the specified limit for tritium. In addition, Co-60 was detected in one atmospheric deposition sample in Loviisa and Co-60 in two samples and Ru-106 in one sample at Olkiluoto. The activity concentrations of Cs-137 and H-3 observed correspond to those found in samples collected elsewhere in Finland. The Sr-90 results of the composite atmospheric deposition samples for the whole year varied between 0.04 and 0.05 Bq/m^2 (Table 3), which is at the same level or lower than the Sr-90 concentrations observed in the atmospheric deposition samples of the national environmental radiation monitoring in different cities in Finland (Mattila and Inkinen, 2022). The composite annual samples of Loviisa were made from the samples of 11 months, because the samples for December did not arrive at STUK's laboratory.

Table 3. Sr-90 results of the composite annual sample of atmospheric deposition.

Site	Collection period	Sr-90 Bq/m²	Unc. 2 σ
Loviisa			
LPO	31.12.21 – 30.11.22	0.048	11 %
Smoltti	31.12.21 - 30.11.22	0.037	11 %
Olkiluoto			
Weather mast	22.12.21 – 22.12.22	0.036	11 %

6.2 Terrestrial environment

Some radionuclides originating from the power plants were detected only in a few samples collected from the terrestrial environment of the Loviisa and Olkiluoto power plants (sludge from the wastewater treatment plant of the Loviisa power plant area and landfill run-off at Olkiluoto). The Cs-137 concentrations in the terrestrial environment samples varied between samples. However, the concentrations of radionuclides were small and insignificant in view of the radiation exposure of the environment.

Moss, fern and lichen effectively collect radionuclides from their environment and, in some places, these plants can show even high concentrations of Cs-137 originating mainly from the Chernobyl disaster. In previous years, high Cs-137 activity concentrations have been observed in plants in the terrestrial environment of Loviisa, and this year's results do not differ from those of previous years. The activity concentrations of Cs-137 detected in ferns (Figure 10) originate at least mainly from the fallout caused by the Chernobyl nuclear power plant accident in 1986. The emission originating from the nuclear power plant also includes shorter-lived Cs-134 with the half-life of 2.06 years. Small amounts of Cs-134 were detected in fern samples up until the early 2010s. Based on the activity concentrations of the isotopes, they probably originated from Chernobyl. Even though higher concentrations have since been observed again, Cs-134 has not been detected anymore. Based on this, the higher activity concentrations are probably not from a new and more recent source. The ferns' activity concentrations in relation to Cs-137 also varied greatly even within very small areas. Good examples of this are the samples collected in 2021 in Loviisa within a couple of kilometres from each other with an approximately 10-time difference in their activity concentrations. At Olkiluoto, the sampling place has been varied as a result of poor growth of common polypody and in 2018, the sampling species had to be changed to ostrich fern. (Table 4.)

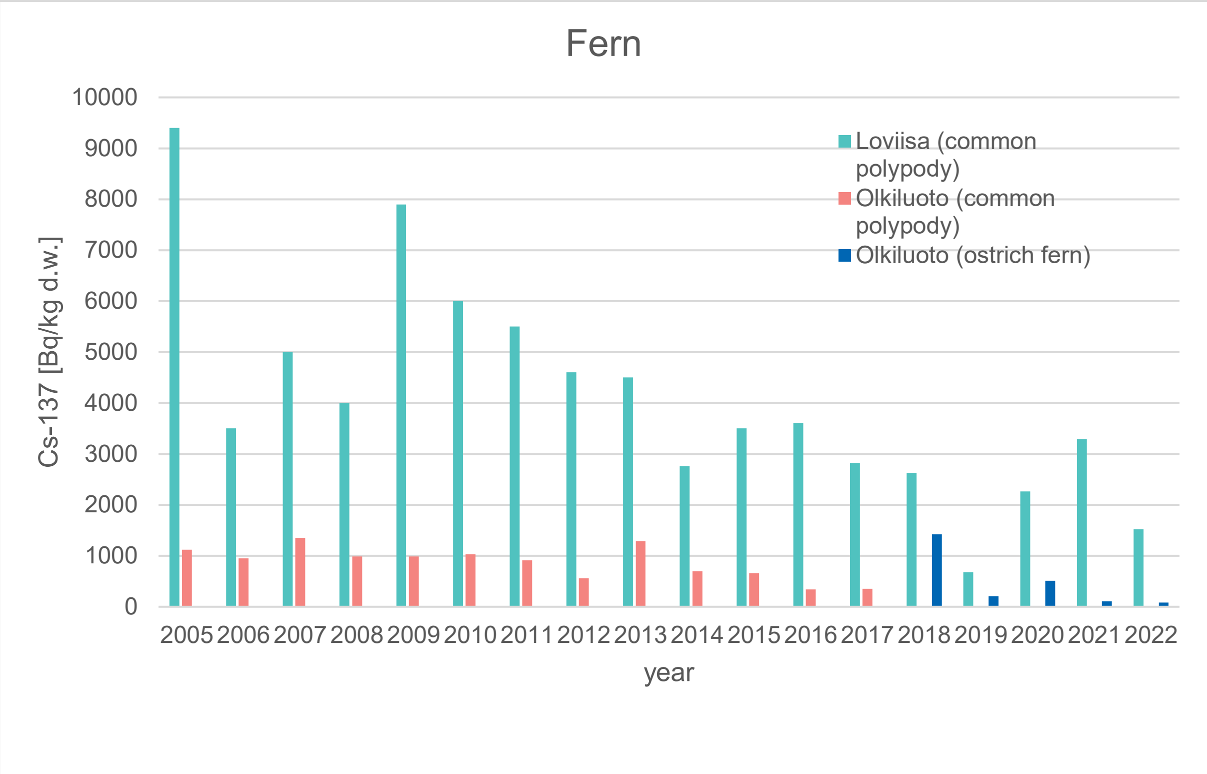

Figure 10. Cs-137 activity concentrations [Bq/kg per dry weight] of fern samples collected from Loviisa and Olkiluoto in 2005–2022.

The licensee collected haircap moss, reindeer lichen, fern and spruce tip samples from the Olkiluoto surroundings. In these samples, only natural nuclides and Cs-137 were detected. The Cs-137 activity concentrations of the samples collected by the licensee were clearly lower or at the same level as the activity concentrations measured in STUK's monitoring programme samples. In the surroundings of the Loviisa power plant, the licensee collected a sample of ferns (common polypody), which showed no nuclides originating from the power plant. The Cs-137 concentration of the fern sample was 2600 Bq/kg.

Table 4. Monitoring measurement results of the lichen, moss, needle and fern samples in 2022. Haircap moss could not be collected from Loviisa and it was replaced by fern.

Site	Collection date	Be-7 Bq/kg	Unc. 2σ	Cs-137 Bq/kg	Unc. 2σ	C-14 Bq/kg	Unc. 2σ	Sr-90 Bq/kg	Unc. 2σ
Spruce needles									
Loviisa	9.6.22	12	24%	300	10%	120	8%	-	
Olkiluoto	1.6.22	5.3	26%	120	10%	120	8%	-	
Reference, Heijalanpää, Kouvola	6.6.22	7.6	20%	95	9%	130	8%	-	
Reindeer lichen									
Loviisa	13.7.22	180	10%	210	10%	-		-	
Olkiluoto	20.7.22	190	9%	110	9%	-		-	
Reference, Jaala	25.7.22	210	9%	260	9%	-		-	
Haircap moss									
Loviisa	replaced by fern								
Olkiluoto	19.7.22	340	9%	350	9%	-		-	
Fern									
Loviisa, Hästholmen (common polypody)	13.7.22	29	14%	1500	8%	-	-	3.7	9%
Loviisa, Källa (common polypody)	26.7.22	54	11%	1300	8%	-	-	-	-
Reference, Linlo, Kirkkonummi (common polypody)	5.7.22	27	19%	94	13%	-	-	6.0	9%
Olkiluoto (ostrich fern)	19.7.22	310	9%	85%	9%	-	-	4.1	9%
Reference, Jaala (ostrich fern)	25.7.22	190	10%	540	9%			8.0	9%

The Cs-137 activity concentrations of mushroom samples collected in the vicinity of the Loviisa and Olkiluoto power plants varied between 0.21 and 230 Bq/kg per fresh weight (Table 5). Following the Chernobyl fallout, mushroom samples may occasionally show elevated concentrations of Cs-137 and, in the case of specific mushroom species (such as milk caps), it is common to find exceedances of 600 Bq/kg also in areas of minor fallout (Kostiainen and Ylipieti, 2010). The EU-recommended limit value for natural food placed on the market is 600 Bq/kg (Commission Recommendation 2003/274/EC). Berry samples collected in the vicinity of the power plants and game meat samples (elk meat) obtained from local hunters had low activity concentrations of less than 30 Bq/kg per fresh weight.

Table 5. Monitoring measurement results of the mushroom, berry and game samples in 2022.

Site	Collection date	Species	Cs-137 Bq/kg FW	Unc. 2σ
Mushrooms				
Loviisa	4.10.22	slippery jack	71	7%
	11.10.22	bovine bolete	49	7%
	11.10.22	conifer tuft	5.3	7%
	11.10.22	ink cap	0.21	17%
Olkiluoto	16.8.22	chanterelle	77	6%
	16.9.22	velvet bolete	150	6%
	16.9.22	slippery jack	140	6%
	29.9.22	woolly milk cap	52	16%
	29.9.22	sweet tooth	230	13%
	21.10.22	sheep polypore	5.3	7%
Berries				
Loviisa	26.7.22	bilberry	15	6%
	7.9.22	lingonberry	17	13%
	7.9.22*	lingonberry	12	13%
Olkiluoto	16.9.22	bilberry	4.3	7%
	16.9.22	lingonberry	14	12%
	16.9.22*	lingonberry	15	12%
Game				
Loviisa	15.12.22	elk	28	8%
Olkiluoto	23.10.22	elk	20	6%
	23.10.22	elk, liver	18	6%

* Quality control sample

The Cs-137 activity concentrations of milk samples varied between 0.05 and 0.55 Bq/l (Table 6) in the environmental radiation monitoring programmes of the nuclear power plants. The Sr-90 activity concentration of the milk sample combined from samples for the whole year (20–40 km from the power plants) was 0.02 Bq/l in both the Loviisa and Olkiluoto sample. The activity concentrations are well in line with the activity concentrations of the national environmental monitoring of milk samples, which were between 0.12 and 0.61 Bq/l for Cs-137 and between 0.02 and 0.03 Bq/l for Sr-90 in 2021 (Mattila and Inkinen, 2022). Figures 11 and 12 show the Cs-137 activity concentration in milk samples of the environmental monitoring programmes of the nuclear power plants in 2010–2022. Every third month, I-131 was also screened from the samples delivered from dairy farms within a distance of 20 km from the power plants. I-131 was not detected in any of the milk samples (limit of determination 0.009–0.08 Bq/l).

In the monitoring programme, the monitoring measurements of the terrestrial environment agricultural products (crops and root vegetable) and grazing grass showed no radionuclides originating from the power plants (Table 7). The Cs-137 activity concentration of the samples was low. The Sr-90 activity concentration of the Olkiluoto crop sample (wheat) was 0.20 Bq/kg. The crop samples from Loviisa arrived too late for the Sr analysis. The C-14 content of grazing grass was 110 Bq/kg in both Loviisa and Olkiluoto and 120 Bq/kg in the reference sample (Jaala, Kimola). No radionuclides originating from the power plants were detected in the apple sample from the surroundings of Loviisa in the monitoring programmes of the licensees. The lettuce sample could not be collected from Olkiluoto due to drought.

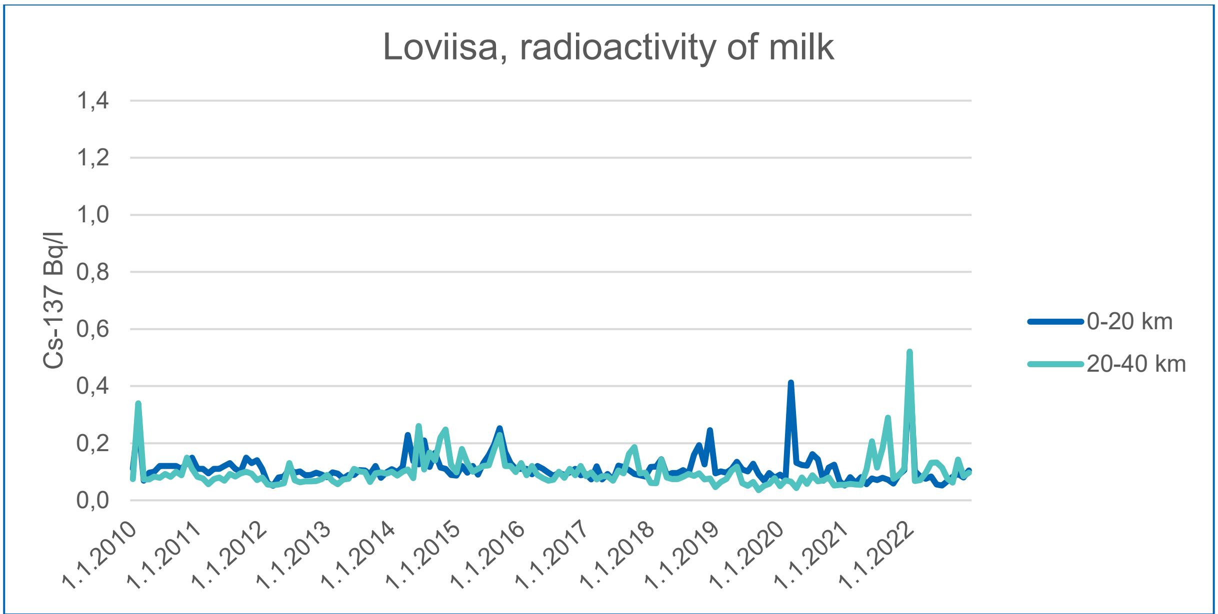

Figure 11. The Cs-137 concentration (Bq/l) of the milk samples supplied by dairies in the surroundings of the Loviisa power plant (distance of the farms from the plant 0–20 km or 20–40 km) in 2010–2022.

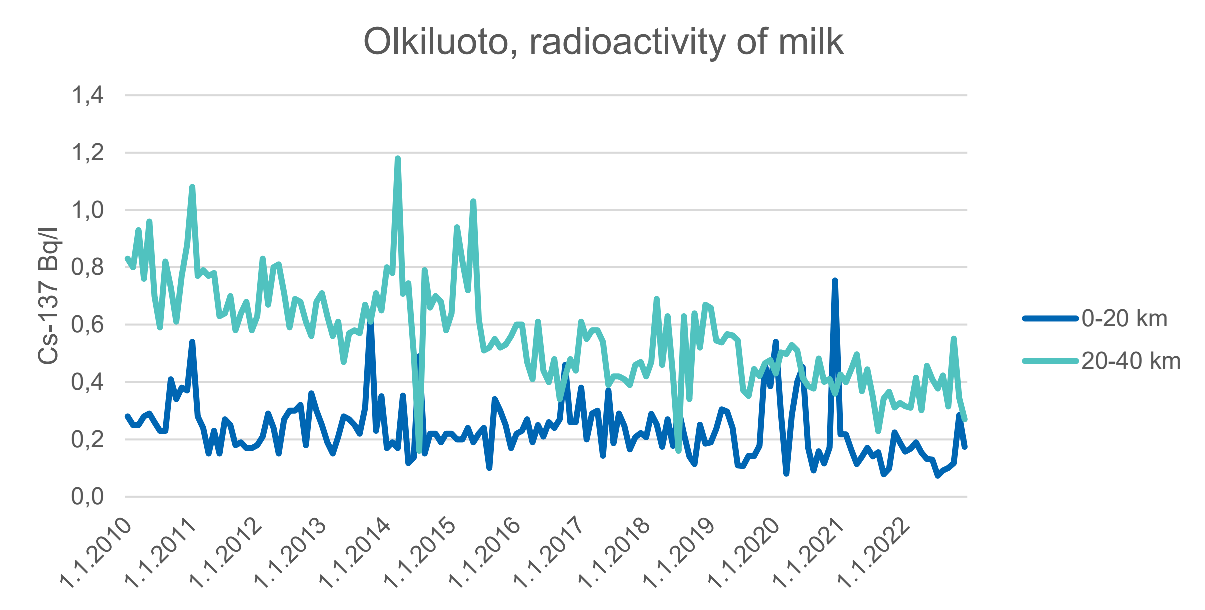

Figure 12. The Cs-137 concentration (Bq/l) of the milk samples supplied by dairies in the surroundings of the Olkiluoto power plant (distance of the farms from the plant 0–20 km or 20–40 km) in 2010–2022.

Table 6. Results of the radioactivity monitoring of the milk samples from the dairies in the surroundings of the Loviisa and Olkiluoto nuclear power plants in 2022.

		0–20 km				20–40 km			
Locality	**Collection period**	**K-40 Bq/l**	**Unc. 2σ**	**Cs-137 Bq/l**	**Unc. 2σ**	**K-40 Bq/l**	**Unc. 2σ**	**Cs-137 Bq/l**	**Unc. 2σ**
Loviisa	27.12.21-30.1.22	49	13%	0.47	18%	46	17%	0.52	16%
	6.-27.2.22	46	10%	0.10	10%	47	10%	0.07	12%
	6-27.3.22	48	16%	0.08	20%	49	13%	0.07	19%
	3.-24.4.22	46	8%	0.08	14%	48	14%	0.10	11%
	1.-29.5.22	52	8%	0.08	11%	48	9%	0.13	12%
	5.-26.6.22	49	8%	0.06	15%	50	13%	0.13	11%
	3.-31.7.22	49	8%	0.05	13%	46	14%	0.12	12%
	7.-28.8.22	52	8%	0.07	12%	48	14%	0.08	11%
	4.-25.9.22	50	7%	0.08	9%	46	11%	0.06	13%
	2.-30.10.22	49	10%	0.09	11%	49	14%	0.14	11%
	30.10.-27.11.22	50	13%	0.08	12%	52	9%	0.08	11%
	28.11.-25.12.22	49	14%	0.10	17%	48	10%	0.10	15%
Olkiluoto	27.12.21-30.1.22	45	12%	0.16	13%	50	17%	0.32	17%
	6.-27.2.22	45	15%	0.17	11%	51	9%	0.31	12%
	6.-27.3.22	48	14%	0.19	14%	49	9%	0.41	9%
	3.-24.4.22	46	8%	0.15	10%	47	7%	0.30	7%
	1.-29.5.22	48	14%	0.13	13%	51	14%	0.46	7%
	5.-26.6.22	52	8%	0.13	10%	49	13%	0.41	8%

	3.-31.7.22	49	8%	0.07	12%	51	8%	0.38	7%
	7.-28.8.22	49	8%	0.09	12%	51	8%	0.42	7%
	4.-25.9.22	51	11%	0.10	11%	48	8%	0.31	8%
	2.-30.10.22	56	8%	0.12	9%	51	13%	0.55	8%
	30.10.-27.11.22	53	8%	0.28	10%	50	10%	0.35	10%
	28.11.-25.12.22	52	8%	0.17	11%	50	9%	0.27	8%

Table 7. Monitoring measurement results of the grazing grass, crop and root vegetable samples in 2022. Root vegetable samples could not be obtained from Loviisa in 2022.

Site	Collection date	Species	K-40 Bq/kg	uncertainty 2σ	Cs-137 Bq/kg	uncertainty 2σ
Grazing grass						
Loviisa	13.7.22	grazing grass	720	17%	0.3	46%
Olkiluoto	20.7.22	grazing grass	480	17%	0.5	28%
Reference, Jaala, Kimola	25.7.22	grazing grass	390	15%	4.8	16%
Crops						
Loviisa	19.12.22	wheat	130	7%	0.22	13%
	19.12.22	oat	140	8%	0.63	9%
Olkiluoto	10.11.22	wheat	150	12%	0.21	60%
	10.11.22	oat	110	14%	0.93	22%
Root vegetable						
Loviisa	-	-				
Olkiluoto	30.9.22	potato	120	14%	0.05	24%

The H-3, Sr-90 and Cs-137 activity concentrations in the domestic water of the cities of Rauma and Loviisa and the Sr-90 activity concentrations in the domestic waters of the power plants supplied by the licensees were at the same level as domestic water concentrations elsewhere in Finland (Table 8). The monitoring programmes of the licensees determined the radionuclides emitting gamma radiation in the domestic water of the power plants four times a year. No radionuclides originating from the power plants were detected in the domestic water of the power plants. The H-3 activity concentrations of all domestic water samples were less than 2 Bq/l. The concentrations correspond to the H-3 concentrations measured in domestic water elsewhere in Finland.

Table 8. Monitoring measurement results of the domestic water of the cities of Rauma and Loviisa in 2022.

Site	Collection date/period	H-3 Bq/l	Unc. 2σ	Sr-90 Bq/m^3	Unc. 2σ	Cs-137 Bq/m^3	Unc. 2σ
Loviisa	1.7.22	1.1	60%	-		< 0.31	
	23.9.22	< 1.1		-		< 0.5	
	1.7.-23.9.22	-		1.0	17%	-	
Loviisa power plant	1.3.-30.11.22*	-		3.0	17%	-	
Rauma	28.6.22	< 1.0		-		1.6	16%
	8.12.22	< 1.1		-		1.5	22%
	28.6.-8.12.22	-		3.6	17%	-	
Olkiluoto power plant	21.1.-9.11.22*	-		2.9	17%	-	

*Composite annual sample, only Sr-90 to be determined

No artificial radionuclides were found in the groundwater samples taken in the surroundings of Loviisa and Olkiluoto. In Olkiluoto, one sludge sample was taken in January and another during the annual outage in June at UPM Rauma's wastewater treatment plant. No artificial radionuclides were detected in the samples, with the exception of Cs-137. Two sludge samples were taken at the Vårdö wastewater treatment plant near Loviisa, one in January and the other during the annual outage in September. The following artificial radionuclides were detected in the samples: I-131, Cs-137, Lu-177 and Tl-201. These same radionuclides are also detected in the samples taken annually from the Viikinmäki wastewater treatment plant in Helsinki, and they are common nuclides used in radionuclide therapy in hospitals, for which reason they are likely to have originated from patients who have received radionuclide therapy. In Loviisa, sludge samples are examined in the licensee's own programme at the wastewater treatment plant at the Loviisa power plant site four times a year, during annual outages and outside these times. The following artificial radioactive substances originating from the power plant were found in these sludge samples: Mn-54, Co-60, Ag-110m and Sb-124. At Olkiluoto, the licensee collected a water sample from the aeration tank of the Olkiluoto landfill, and this sample contained a small amount of Co-60 (4 Bq/m^3).

The soil samples included in STUK's monitoring programme are collected every two years from the surroundings of the power plants. No radionuclides originating from the power plants were detected in the soil samples collected from the surroundings of Loviisa and Olkiluoto in 2022 (Tables 9 and 10).

Table 9. Monitoring measurement results of the Loviisa soil samples (surface layer 0–5 cm) in 2022.

Site	Date	K-40 Bq/kg	Unc. 2σ	Co-60 Bq/kg	Unc 2σ	Sr-90 Bq/kg	Unc. 2σ	Ag-110m Bq/kg	Unc 2σ	Cs-137 Bq/kg	Unc. 2σ
Ingersholm	6.6.2022	990	8%	< 0.2		1.6	10%	< 0.2		39	7%
Bölsängen	6.6.2022	690	14%	< 0.3		1.0	10%	< 0.4		250	6%
Källa	9.6.2022	1,000	8%	< 0.3		2.0	10%	< 0.3		48	7%
Hudö G	9.6.2022	640	11%	< 0.2		1.5	10%	< 0.3		310	7%
Tallholmen	10.6.2022	620	10%	< 0.3		7.0	10%	< 0.4		700	7%

Table 10. Monitoring measurement results of the Olkiluoto soil samples (surface layer 0–5 cm) in 2022.

Site	Date	K-40 Bq/kg	Unc. 2σ	Co-60 Bq/kg	Unc 2σ	Sr-90 Bq/kg	Unc. 2σ	Ag-110m Bq/kg	Unc 2σ	Cs-137 Bq/kg	Unc. 2σ
Itäranta	1.6.2022	440	10%	< 0.3		3.3	10%	< 0.3		95	6%
Munakari	1.6.2022	770	9%	< 0.3		2.4	10%	< 0.3		51	6%
Flutanperä 2	1.6.2022	210	13%	< 0.3		3.0	10%	< 0.4		280	7%
Viinitarha	1.6.2022	600	8%	< 0.2		1.1	10%	< 0.2		150	7%
Kuusisenmaa	1.6.2022	580	10%	< 0.2		2.5	10%	< 0.2		62	6%

6.3 Marine environment

Some radionuclides originating from the power plants were detected from the samples collected from the marine environment of the Loviisa and Olkiluoto power plants. However, the concentrations of radionuclides were small and insignificant in view of the radiation exposure of the environment.

Tables 11 and 12 show the monitoring measurement results of the seawater samples in 2022. The results are presented in order of distance from the discharge opening, showing the results closest to the discharge opening at the beginning of the tables.

The seawater samples collected from the surroundings of both power plants showed activity concentrations of H-3 exceeding 2 Bq/l, but the concentrations remained under 10 Bq/l with the exception of four samples. The Loviisa seawater sample for January was taken during the discharge of process water and does not represent the normal activity concentration of the area. In the future, the discharge dates will be determined from the plant staff in order to avoid sampling immediately after the discharge. The typical concentration of tritium was 1–2 Bq/l in seawater of the Baltic Sea area in 2011–2015 (HELCOM 2018). Based on the long-term results of the Baltic Sea area, the background level for the tritium concentration is less than 2 Bq/l for the seawater, rainwater and domestic water samples in the environmental radiation monitoring of the Olkiluoto and Loviisa power plants. Tritium concentrations above this background level are attributed to releases from the power plants. The Sr-90 and Cs-137 activity concentrations in the seawater samples were at a usual Baltic Sea level.

In the longer time series (Figures 13 and 14), it can be seen that the most significant source of Cs-137 in seawater is the Chernobyl disaster in 1986. The effect of normal releases from the plants cannot be distinguished from the activity originating from the Chernobyl disaster as the Cs-137 concentrations of seawater correspond to the common activity concentration of Cs-137 in the Baltic Sea (HELCOM 2018).

The Cs-137 concentrations of the seawater samples taken by the licensees corresponded to the common activity concentration of Cs-137 in the Baltic Sea. The concentration of H-3 in seawater was in the licensee’s measurements between 1.5 and 2.2 Bq/l in Loviisa and between 1.1 and 61 Bq/l in Olkiluoto. The high H-3 activity concentration (61 Bq/l) in the seawater sample taken in Olkiluoto in the spring is explained by the fact that the sample was taken at the same time with the process water discharge. In other respects, the analysis results of the seawater samples taken by the licensees corresponded to the results of the samples taken by STUK.

Table 11. Monitoring measurement results of the Loviisa seawater samples in 2022.

Site	Collection date	H-3 Bq/l	Uncertainty 2σ	Sr-90 Bq/m³	Uncertainty 2σ	Cs-137 Bq/m³	Uncertainty 2σ
Halkokari 02	12.1.2022	221	10%	5.5	15%	12	16%
	27.4.2022	2.4	30%	5.5	10%	13	14%
	24.8.2022	2.4	34%	6.2	10%	13	17%
	17.11.2022	2.1	36%	5.5	10%	12	13%
Klobbfjärden 1	27.4.2022	5.9	17%	-		9.4	14%
	17.11.2022	3.9	22%	-		13	11%
Vådholmsfjärden 4	28.4.2022	66	10%	-		12	12%
	16.11.2022	2.0	36	-		13	7%
Hudöfjärden 8	28.4.2022	1.3	50%	-		11	15%
	16.11.2022	2.1	36	-		12	12%
Påsalöfjärden R1	28.4.2022	1.3	50%	4.1	10%	9.2	18%
	16.11.2022	< 1.1		5.2	10%	10	14%

Table 12. Monitoring measurement results of the Olkiluoto seawater samples in 2022.

Site	Collection date	H-3 Bq/l	uncertainty 2σ	Sr-90 Bq/m³	uncertainty 2σ	Cs-137 Bq/m³	uncertainty 2σ
Iso Kaalonperä 13	18.1.2022	18	12%	5.8	14%	17	15%
	21.4.2022	< 1.0		5.7	10%	18	13%
	18.8.2022	< 1.2		6.7	10%	20	13%
	10.11.2022	22	11%	5.5	10	21	8%
Liponluoto 2	21.4.2022	1.2	56%	-		16	12%
	8.11.2022	< 1.1		-		18	10%
Rääpinkivet 3	5.5.2022	2.1	34%	-		16	13%
	10.11.2022	< 1.1		-		19	9.810%
Santakari 15	4.5.2022	< 1.0		-		16	16%
	9.11.2022	< 1.1		-		17	9%
Kylmäpihlaja 17	5.5.2022	< 1.0				21	14%
	10.11.2022	< 1.1				17	9%
Viikari 16	12.5.2022	< 1.0		5.7	10%	17	16%
	10.11.2022	< 1.1		5.6	10%	17	7%

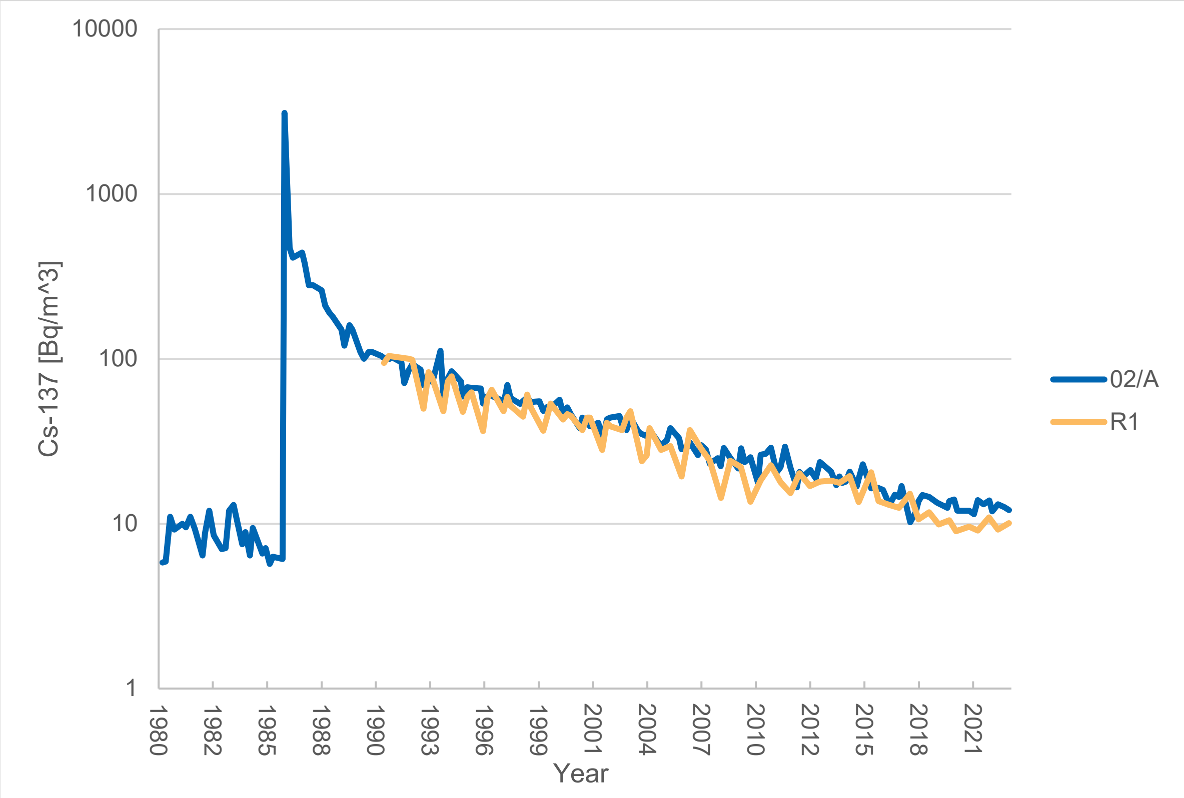

Figure 3. The Cs-137 activity concentration in seawater at the nearest (02/A, blue) and furthest (R1, yellow) sampling point of the Loviisa power plant between 1980 and 2022 presented on a logarithmic scale.

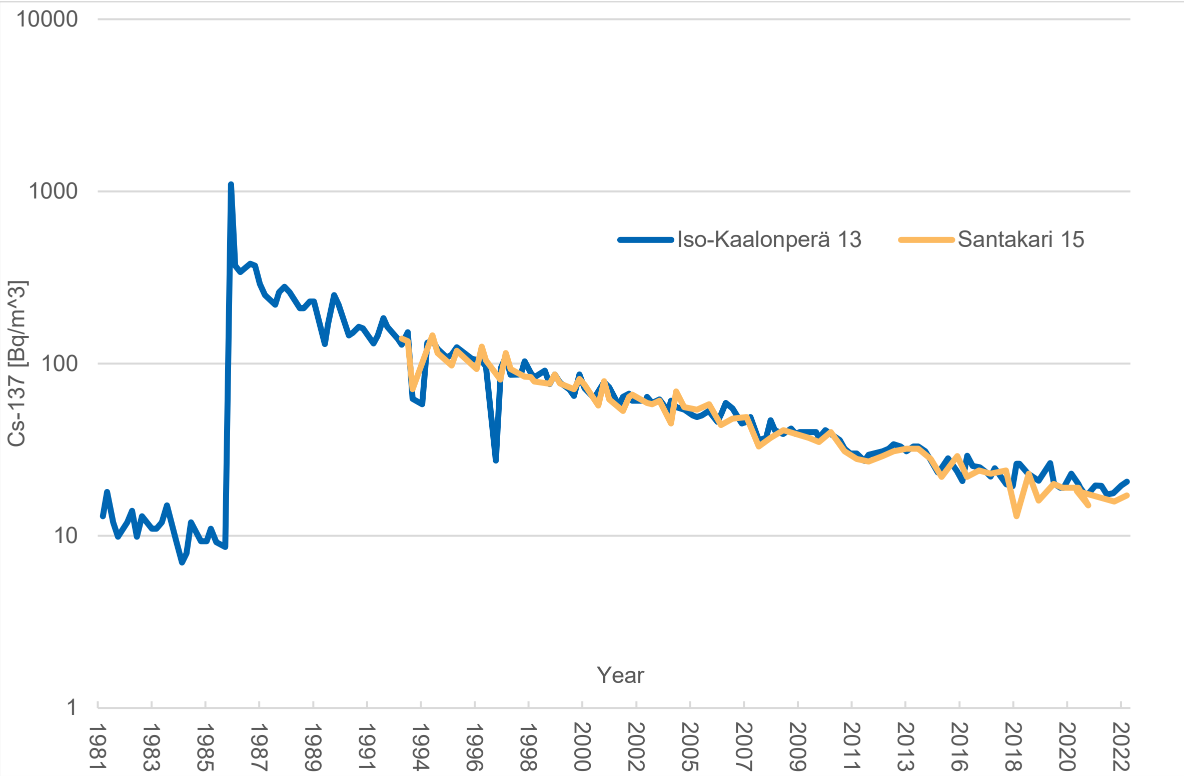

Figure 4. The Cs-137 activity concentration in seawater at the nearest (Iso Kaalonperä 13, blue) and furthest (Santakari 15, yellow) sampling point of the Olkiluoto power plant between 1981 and 2022 presented on a logarithmic scale.

Fishing in the vicinity of the power plants takes place at two different distances from the power plants: in Loviisa the fishing areas are 0–2 km and 2–10 km from the plant and in Olkiluoto 0–3 km and 3–10 km from the plant. The Baltic herring is fished at the distance of 0–10 km. The Cs-137 concentrations of fish samples (Baltic herring, roach, perch, pike and bream) varied between 1.6 and 10.1 Bq/kg (per fresh weight, Table 13). The concentrations were low and well in line with the Cs-137 activity concentrations in the fish and reference samples of the Baltic Sea area (HELCOM 2018, Mattila and Inkinen, 2022). The concentrations of Sr-90 in the fish samples were also low. The Cs-137 activity concentration in the fry sample received from the Smoltti fish farm in Loviisa was very low.

The radioactivity concentrations of the benthic fauna samples (gulf wedge clam and blue mussel) were low (Table 14). The gulf wedge clam sample from the surroundings of Loviisa contained Ag-110m originating from the power plant, but the concentration was low and does not affect the radiation exposure of the biota.

Table13. Monitoring measurement results of the fish samples from the marine environment of Loviisa and Olkiluoto in 2022.

Sample type	Site	Collection period	Cs-137 Bq/kg	Uncertainty 2σ	Sr-90 Bq/kg	Uncertainty 2σ
Baltic herring	Loviisa 0–10 km	25.10.22	1.9	8%	0.022	18%
	Olkiluoto 0–10 km	29.9-18.10.22	3.2	24%	0.019	20%
Perch	Loviisa 0–2 km	19.5.22	7.9	9%	0.011	26%
	Loviisa 2–10 km	24.5.-5.10.22	7.7	7%	-	
	Olkiluoto 0–3 km	12.5.-1.6.22	9.0	7%	< 0.004	
	Olkiluoto 3–10 km	18.8.22	10.1	7%	-	
Pike	Loviisa 0–2 km	7.6.-21.9.22	4.2	7%	-	
	Loviisa 2–10 km	7.6.-7.9.22	5.3	7%	-	
	Olkiluoto 0–3 km	12.5.-1.6.22	5.8	7%	-	
	Olkiluoto 3–10 km	31.8.-13.9.22	6.0	7%	-	
Bream	Loviisa 0–2 km	19.5.-24.5.22	1.6	10%	-	
	Loviisa 2–10 km	8.6.22	1.6	9%	-	
	Olkiluoto 3–10 km	31.5.22	2.0	8%	-	
Roach	Olkiluoto 0–3 km	30.9.-18.10.22	2.4	8%		
Fry sample (common whitefish)	Loviisa, Smoltti	8.9.22	0.15	28%	-	

Table 14. Monitoring measurement results of the benthic fauna collected from the marine environment of Loviisa and Olkiluoto in 2022.

Sample type	Site	Collection period	Sr-90 Bq/kg	2σ	Ag-110m Bq/kg	2σ	Cs-137 Bq/kg	2σ
Gulf wedge clam	Halkokari, Loviisa	22.9.22	8.3	11%	0.3	52%	1.1	14%
Gulf wedge clam	Kasabergsudden, Loviisa	22.9.22	7.7	11%	< 0.6		< 0.6	
Gulf wedge clam	Iso Kaalonperä, Olkiluoto	27.9.22	7.4	11%	< 0.1		0.2	42%
Blue mussel	Olkiluoto Iso-Pietari C	15.9.22	6.6	11%	< 0.4		0.9	32%

In the aquatic environment, periphyton, bladder wrack and spiked water milfoil, from among the aquatic plants with submerged leaves, have proven to be particularly good indicators of power plant releases. The longest observation series are of bladder wrack, and they clearly show the impact of power plant releases. However, bladder wrack is sensitive to environmental changes, and collecting it has not been possible every year at the established sampling points. Figures 15 and 16 show the annual averages of the activity concentrations of some of the most significant nuclides originating from the power plants in bladder wrack samples collected nearest the power plants. In the bladder wrack samples, the activity concentrations of the nuclides originating from the power plants have decreased clearly as the power plant releases have decreased. Figures 17 and 18 show the link between the activity concentration of Co-60 in the bladder wrack samples and the Co-60 discharges from the power plants into the sea. Changes in the activity concentrations follow quite closely the changes in the releases; there seems to be a delay of approximately one year in the change in the activity concentrations in the surroundings of the Loviisa power plant. Every four years, the Loviisa power plant carries out discharges of the surface water of the Cs separated evaporation concentrate tanks, which cause, for example, an increase in Co-60 releases. These discharges are scheduled for the end of the year in order to mitigate the effects of nutrients contained in the release. Radioactive substances resulting from the release will therefore only be visible in the results of the monitoring of samples for the next growing season. The latest discharge was made in December 2021, and it was reflected to some extent in the 2022 monitoring samples.

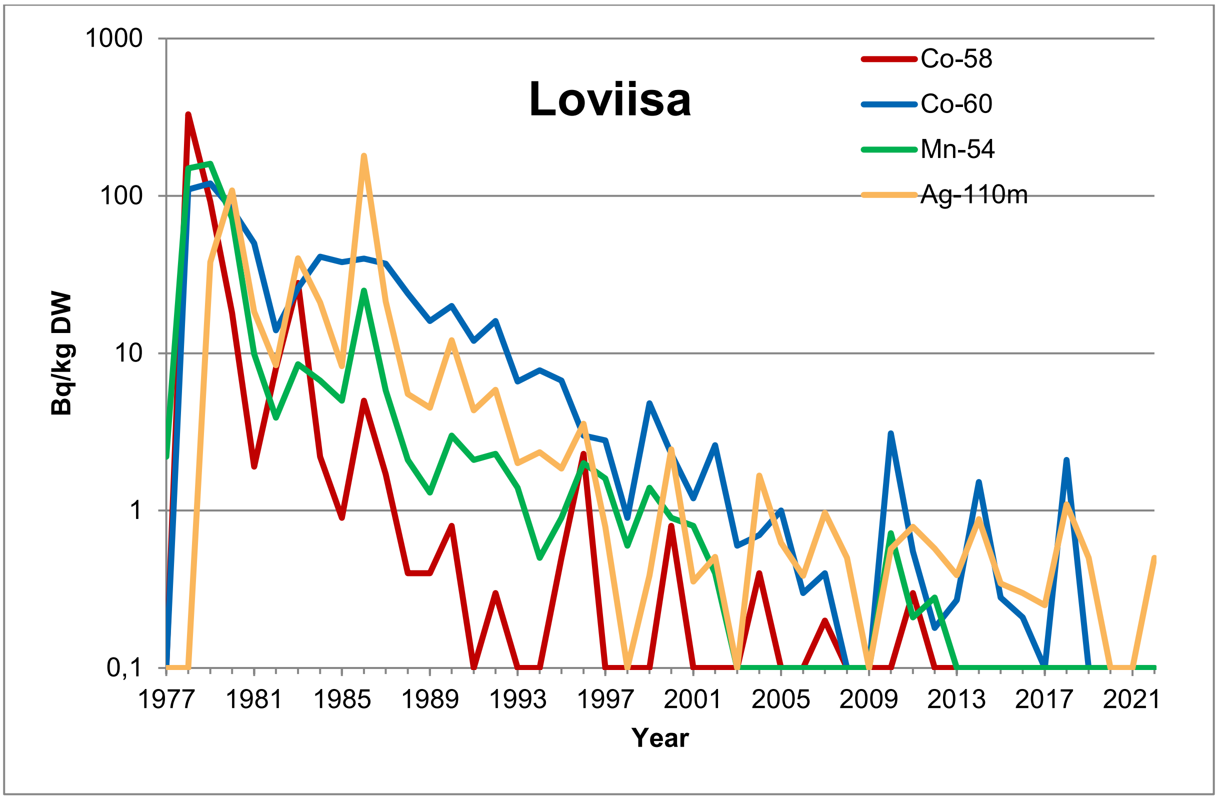

Figure 15. Averages of the activity concentrations of the most significant radionuclides originating from the power plant in bladder wrack (Bq/kg per dry weight) at the nearest sampling point of the Loviisa power plant between 1977 and 2022 on a logarithmic scale.

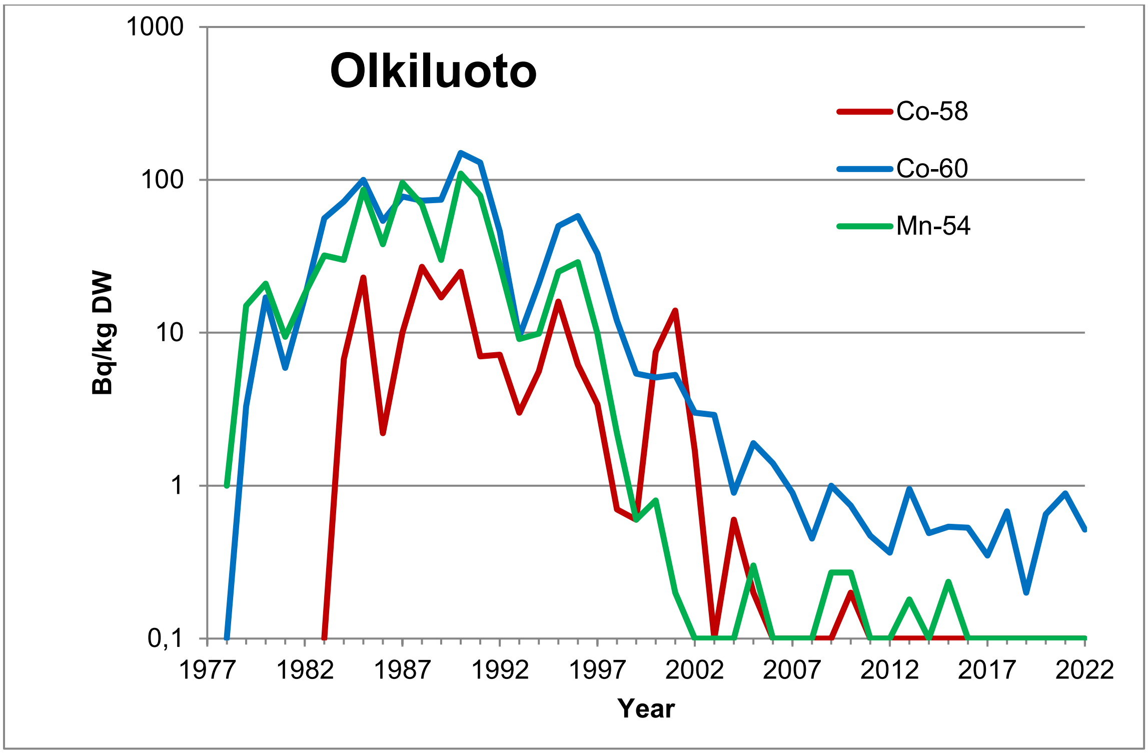

Figure 16. Averages of the activity concentrations of the most significant radionuclides originating from the power plant in bladder wrack (Bq/kg per dry weight) at the nearest sampling point of the Olkiluoto power plant between 1977 and 2022 on a logarithmic scale.

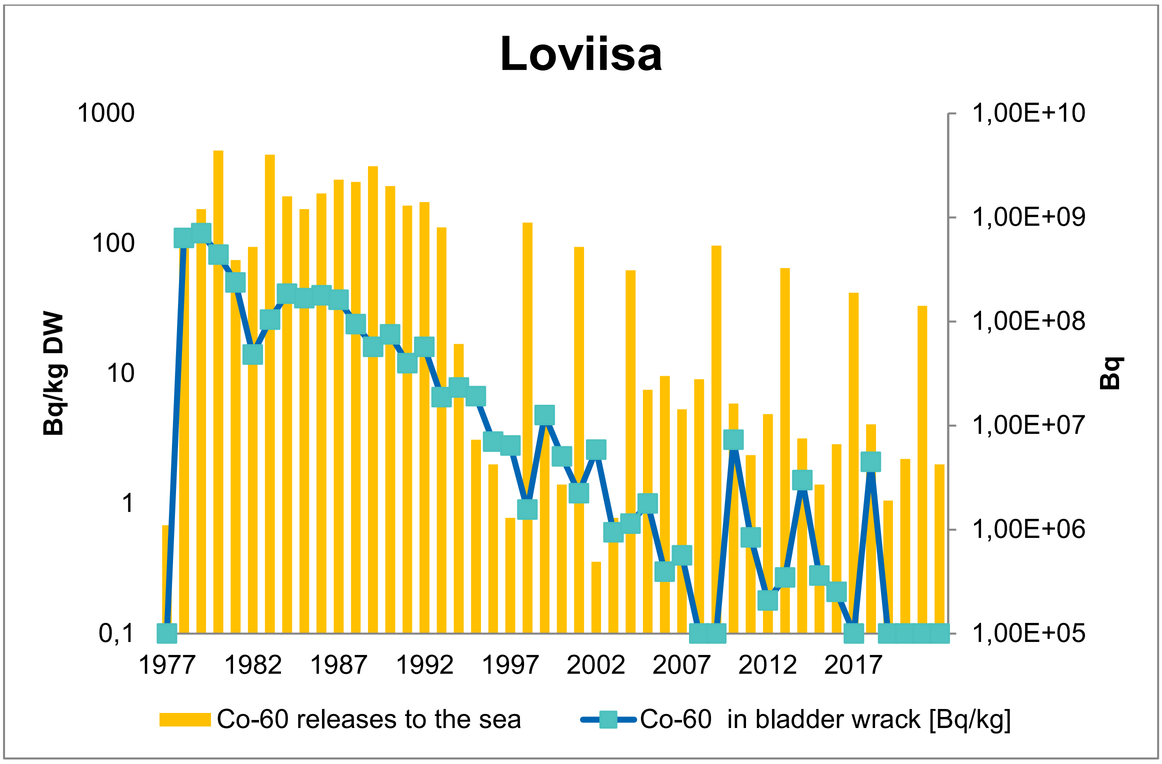

Figure 17. The Co-60 releases into the sea and the average of the Co-60 activity concentration in the bladder wrack samples of the nearest sampling point of the Loviisa power plant between 1977 and 2022.

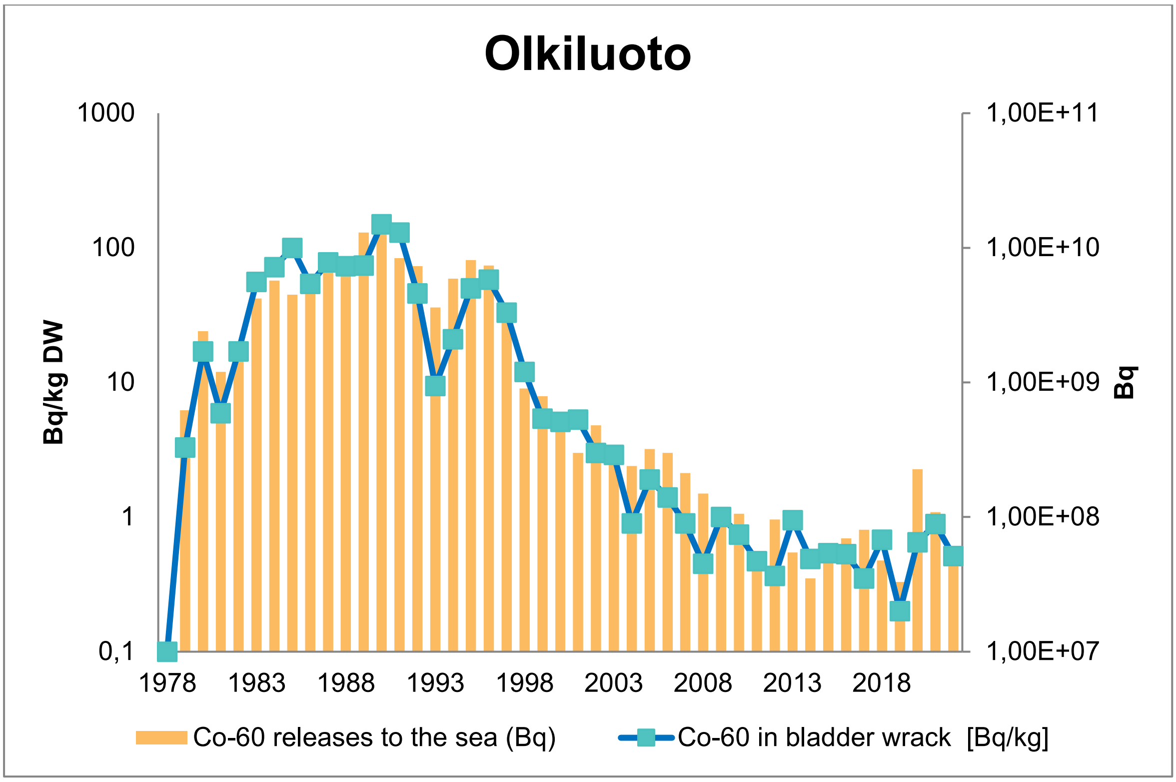

Figure 5. The Co-60 releases into the sea and the average of the Co-60 activity concentration in the bladder wrack samples of the nearest sampling point of the Olkiluoto power plant between 1977 and 2022.

The results of the periphyton samples are given in Annex 4. Several radionuclides originating from the power plants were found in the periphyton samples, but their concentrations were low. The nuclides originating from the power plants found in the periphyton samples of Loviisa were Mn-54, Co-58, Co-60, Nb-95, Zr-95, Ag-110m, Te-123m, Sb-124, Cs-137 and Hf-181, and those of Olkiluoto were Mn-54, Co-58, Co-60 and Cs-137. In addition to periphyton samples, Co-58 and Co-60 were also detected in bladder wrack in Olkiluoto (Tables 15 and 16). A small amount of Ag-110m was also detected in one bladder wrack sample from Loviisa. The Cs-137 activity concentrations of bladder wrack varied in Loviisa between 9.3 and 17.5 Bq/kg and in Olkiluoto between 7.8 and 14.8 Bq/kg per dry weight. The same nuclides originating from the power plants have been observed in the periphyton and bladder wrack samples as in the previous years and the activity concentrations do not differ from the those measured in the previous years. The nuclides found in the samples are the same that the power plants have reported to have discharged into seawater on the basis of their own release measurements.

Small quantities of radionuclides originating from the power plants were observed in spiked water milfoil (Tables 17 and 18). Co-58, Co-60, Ag-110m, Te-123m and Sb-124 were detected in the spiked water milfoil samples collected from the discharge area of the Loviisa power plant and Mn-54, Co-58 and Co-60 were detected in the spiked water milfoil samples collected from the Olkiluoto discharge area. The Cs-137 activity concentrations of the spiked water milfoil samples varied in Loviisa between 11.7 and 13.0 Bq/kg per dry weight and in Olkiluoto between 8.5 and 10.6 Bq/kg per dry weight. The reference samples of spiked water milfoil were collected further away from the discharge opening but still in the vicinity of the power plant (Strömslandet in Loviisa and Keskuskari in Olkiluoto), and radionuclides originating from the power plants were no longer found in these samples, indicating that the activity concentrations of the radionuclides are lower further away from the discharge opening.

Table 15. Radionuclides found in the bladder wrack samples collected in the marine environment of Loviisa in 2022.

Sampling point	Collection date	Cs-137 Bq/kg DW	Unc. 2σ	Sr-90 Bq/kg DW	Unc. 2σ	Ag-110m Bq/kg DW	Unc. 2σ
Stenörarna	17.5.2022	17.5	8%	4.1	11%	< 0.5	
	22.9.2022	11.5	12%	-		< 0.3	
Hästholmen SW	17.5.2022	14.0	7%	-		0.5	24%
	22.9.2022	11.2	8%	-		< 0.5	
Lilla Djupberget	18.5.2022	11.7	18%	-		< 0.3	
	8.9.2022	12.0	13%	-		< 0.2	
Boistö	18.5.2022	10.7	8%	-		< 0.5	
	8.9.2022	13.0	10%	-		< 0.2	
Storskarven	18.5.2022	11.8	8%	4.1	11%	< 0.4	
	8.9.2022	9.3	11%	-		< 0.2	

Table 16. Radionuclides found in the bladder wrack samples collected in the marine environment of Olkiluoto in 2022.

Site	Collection date	Co-58 Bq/kg DW	Unc. 2σ	Co-60 Bq/kg DW	Unc. 2σ	Cs-137 Bq/kg DW	Unc. 2σ	Sr-90 Bq/kg DW	Unc. 2σ
Iso Kaalonperä 9	10.5.2022	< 0.22		0.70	19%	14.4	11%	4.9	11%
	27.9.2022	0.18	50%	0.33	34%	14.8	13%	-	
Kalliopöllä	10.5.2022	< 0.32		0.50	18%	13.7	8%	-	
	14.9.2022	< 0.09		0.24	26%	9.0	11%	-	
Reimarkrunni	10.5.2022	< 0.18		0.45	24%	10.3	5%	-	
	14.9.2022	0.29	46%	0.32	46%	10.8	11%	-	
Iso-Siiliö	12.5.2022	< 0.25		< 0.25		8.7	11%	-	
	15.9.2022	< 0.15		< 0.19		7.8	11%		
Iso-Pietari	12.5.2022	< 0.29		< 0.35		9.3	8%	-	
	15.9.2022	< 0.15		< 0.20		9.0	10%	-	
Kylmäpihlaja 17	11.5.2022	< 0.16		< 0.18		8.8	10%	-	
	28.9.2022	< 0.13		< 0.16		7.8	10%	-	
Viikari 16	12.5.2022	< 0.16		< 0.20		9.8	9%	4.1	10%
	15.9.2022	< 0.16		< 0.19		10.3	13%	-	

Table 17. Radionuclides found in the spiked water milfoil samples collected in the marine environment of Loviisa in 2022.

Site	Collection date	Co-58 Bq/kg DW	Unc. 2σ	Co-60 Bq/kg DW	Unc. 2σ	Ag-110m Bq/kg DW	Unc. 2σ	Te-123m Bq/kg DW	Unc. 2σ	Sb-124 Bq/kg DW	Unc. 2σ	Cs-137 Bq/kg DW	Unc. 2σ
Halkokari	22.9.2022	< 0.55		< 0.60		1.2	26%	< 0.21		< 0.49		12.8	11%
Tallholmen	22.9.2022	0.45	20%	0.57	36%	1.8	17%	0.12	24%	0.28	50%	11.8	13%
Kasabergs-udden	22.9.2022	< 0.25		< 0.27		0.67	17%	< 0.16		< 0.25		13.0	13%
Strömslandet (reference)	5.10.2022	< 0.12		< 0.13		< 0.13		< 0.08		< 0.12		11.7	5%

Table 18. Radionuclides found in the spiked water milfoil samples collected in the marine environment of Olkiluoto in 2022.

Site	Collection date	Mn-54 Bq/kg DW	Unc. 2σ	Co-58 Bq/kg DW	Unc. 2σ	Co-60 Bq/kg DW	Unc. 2σ	Cs-137 Bq/kg DW	Unc. 2σ
Iso Kaalonperä, breakwater	14.9.2022	0.56	42%	0.50	48%	1.9	16%	8.5	9%
Iso-Kaalonperä, sauna on the waterfront	14.9.2022	< 0.58		1.4	28%	< 0.68		8.5	11%
Keskuskari N (reference)	28.9.2022	< 0.16		< 0.17		< 0.23		10.6	8%

Small concentrations of radionuclides originating from the power plants were found in the sinking matter samples collected from the environment of the power plants (Tables 19 and 20). Co-58, Co-60, Nb-95, Ag-110m, Sb-124 and Cs-137 were detected in Loviisa, and Co-60 and Cs-137 were detected in Olkiluoto. Cs-137 found in the sinking matter originates largely from the Chernobyl disaster. Table 21 presents the activity concentrations of the plutonium isotopes Pu-238 and Pu-239 and 240 detected in the bladder wrack and sediment samples. Sediment and sinking matter show small background concentrations of the Pu-238, Pu-239 and Pu-240 radionuclides originating from the global fallout from the atmospheric nuclear weapons tests. The activity concentrations of Pu-238, Pu-239 and Pu-240 in the samples from the surroundings of the Olkiluoto and Loviisa power plants are at the same level as those commonly found in sediment in the Baltic Sea region (HELCOM, 2018).

Table 19. Radionuclides observed in the sinking matter samples collected from the marine environment of Loviisa in 2022.

Site	Collection period	Co-60 Bq/kg	Unc. 2σ	Ag-110m Bq/kg	Unc. 2σ	Cs-137 Bq/kg	Unc. 2σ
Hästholmsfjärden 5S	18.11.21-27.4.22	4.9	26%	34	14%	250	7%
	27.4.-21.6.22	0.91	18%	3.6	10%	186	7%
	21.6.-6.9.22	1.6	54%	9.3	17%	189	7%
	6.9.-17.11.22*	1.1	34%	4.1	16%	270	7%
Hästholmsfjärden 3	17.11.21-27.4.22	< 1.8		6.5	14%	210	8%
	27.4.-22.6.22	< 0.74		1.6	15%	200	7%
	22.6.-6.9.22	< 1.9		2.5	28%	181	11%
	6.9.-17.1122	0.79	48%	1.7	30%	240	7%
Klobbfjärden 1	17.11.21-27.4.22	< 2.7		8.5	19%	300	7%
	27.4.-22.6.22	< 1.4		< 1.6		250	8%
	22.6.-6.9.22	< 1.1		< 1.4		270	13%
	6.9.-17.11.22	< 0.68		< 0.78		300	7%
Vådholmsfjärden 4	16.11.21-28.4.22	< 1.8		< 2.2		260	10%
	28.4.-21.6.22	< 1.2		< 1.4		133	7%
	21.6.-6.9.22	< 1.8		< 2.4		220	9%
	6.9.-16.11.22	< 0.68		< 0.95		250	7%
Påsalöfjärden R1	16.11.21-28.4.22	< 2.6		< 3.9		240	8%
	28.4.-22.6.22	< 0.67		< 0.86		184	7%
	22.6.-23.8.22	< 0.69		< 0.88		182	12%
	22.6.-23.8.22[a]	< 1.1		< 1.4		184	12%
	6.9.-16.11.22	< 0.36		< 0.54		196	7%

*The sample also contained Co-58: 0.95 ±38%, Nb-95: 2.14 ±32% and Sb-124: 1.17 ±46% Bq/kg per dry weight.

[a]Quality control sample. The collector 10 m from the sample collector.

Table 20. Radionuclides observed in the sinking matter samples collected from the marine environment of Olkiluoto in 2022.

Site	Collection period	Co-60 Bq/kg	Unc. 2σ	Cs-137 Bq/kg	Unc. 2σ
Rääpinkivet 3	26.10.21-5.5.22	0.71	38%	141	7%
	5.5.-16.6.22	< 1.3		103	8%
	16.6.-30.8.22	0.79	34%	126	7%
	30.8.-10.11.22	0.70	24%	130	7%
Vähä Kivikkokari 12	26.10.21-21.4.22	1.3	26%	160	6%
	21.4.-16.6.22	1.9	24%	134	9%
	16.6.-31.8.22	0.49	56%	142	7%
	31.8.-8.11.22	< 0.58		139	7%
Iso Kaalonperä 9	26.10.21-21.4.22	1.3	20%	151	7%
	21.4.-15.6.22	1.4	34%	121	9%
	15.6.-31.8.22	12.7	8%	149	6%
	31.8.-8.11.22	2.0	22%	150	7%
Santakari 15	winter collector lost				
	4.5.-14.6.22	< 1.2		130	7%
	14.6.-30.8.22	< 0.45		141	7%
	30.8.-9.11.22	< 0.77		140	7%
Kuuskajaskari 20	28.10.21-5.5.22	< 0.75		152	7%
	5.5.-16.6.22	< 1.4		141	6%
	16.6.-1.9.22	< 0.62		144	7%
	1.9.-10.11.22	< 1.1		147	10%
Keskivedenkari 18	27.10.21-4.5.22	< 0.41		127	7%
	4.5.-14.6.22	< 0.59		112	7%
	14.6.-30.8.22	< 0.46		123	7%
	14.6.-30.8.22*	< 0.76		127	7%
	30.8.-9.11.22	< 0.73		127	7%

* Quality control sample. The collector 10 m from the sample collector.

Taulukko 21. Activity concentrations of plutonium isotopes Pu-238, Pu-239 and Pu-240 in the composite annual sinking matter samples collected from the marine environments of Loviisa and Olkiluoto in 2022

Site	Site	Collection period	Pu-238 Bq/kg	Unc. 2σ	Pu-239,240 Bq/kg	Unc. 2σ
Loviisa	Hästholmsfjärden 5S	18.11.21 – 17.11.22	<0,032		0,68	13 %
	Påsalöfjärden R1	16.11.21 -16.11.22	<0,024		0,26	16 %
Olkiluoto	Rääpinkivet 3	26.10.21 – 10.11.22	<0,032		0,43	15 %
	Keskivedenkari 18	27.10.21 – 9.11.22	<0,032		0,34	16 %

Table 22. Activity concentrations of the plutonium isotopes Pu-238, Pu-239 and Pu-240 of the bladder wrack samples collected from the marine environment of Loviisa and Olkiluoto in 2022.

Site	Site	Sample type	Collection period	Pu-238 Bq/kg	2σ	Pu-239/240 Bq/kg	2σ
Loviisa	Stenörarna	Bladder wrack	17.5.22	< 0.040		0.076	35%
	Storskarven E	Bladder wrack	18.5.22	< 0.021		0.041	36%
Olkiluoto	Iso Kaalonperä 9	Bladder wrack	10.5.22	< 0.018		0.058	22%
	Viikari 16	Bladder wrack	12.5.22	< 0.036		< 0.030	

Radionuclides originating from the power plants were found in surface sediment in the marine environment of the power plants (Table 22). Co-60 and Ag-110m were detected in Loviisa, and the Cs-137 concentration of sediment in the vicinity of the power plant was between 270 and 350 Bq/kg. Co-60 was detected at Olkiluoto, and the Cs-137 activity concentration of sediment in the vicinity of the power plant was between 160 and 200 Bq/kg. The sediment reference samples were collected further away from the power plants and no radionuclides originating from the power plants were detected in these samples, and the Cs-137 activity concentration of the reference samples was approximately 220 Bq/kg per dry weight.

Table 23. Radioactive substances found in the marine environment sediment samples in 2022.

Site	Collection date	Co-60 Bq/kg	Unc. 2σ	Ag-110m Bq/kg	Unc. 2σ	Cs-137 Bq/kg	Unc. 2σ	Pu-238 Bq/kg	Unc. 2σ	Pu-239/240 Bq/kg	Unc. 2σ
Hästholmsfjärden 5, Loviisa	24.8.22	< 0.62		1.3	18%	330	7%	< 0.044		0.77	32%
Hästholmsfjärden 3, Loviisa	23.8.22	1.6	34%	2.2	26%	270	16%	< 0.036		0.72	34%
Klobbfjärden 1, Loviisa	24.8.22	< 0.50		0.77	24%	350	13%	< 0.023		1.1	24%
Hudöfjärden 10, Loviisa	23.8.22	< 0.77		< 0.82		270	7%	< 0.051		0.67	34%
Påsalöfjärden R1, Loviisa	23.8.22	< 0.40		< 0.45		220	10%	< 0.030		0.34	30%
Vähä Kivikkokari 12, Olkiluoto	18.8.22	0.86	44%	< 0.58		166	7%	< 0.031		0.60	28%
Olkiluoto 9, Olkiluoto	18.8.22	0.82	48%	< 0.61		156	7%	0.252	46%	1.1	28%
Liponluoto 2, Olkiluoto	18.8.22	1.0	52%	< 0.81		168	9%	< 0.031		0.73	26%
Tankarit 4, Olkiluoto	18.8.22	< 0.69		< 0.83		199	16%	< 0.031		0.65	30%
Olkiluoto S8, Olkiluoto	18.8.22	< 0.56		< 0.72		220	14%	< 0.025		< 0.022	

6.4 Inhabitants of the surroundings

No radioactive substances originating from the power plants were detected in the measurements of inhabitants of the area surrounding the power plants. Measurements were made on 28 individuals in Loviisa and 19 in Olkiluoto.

7 Summary and conclusions

A total of approximately 420 samples were collected and analysed from the terrestrial and marine environment surrounding the Loviisa and Olkiluoto power plants in 2022. In 2022, small quantities of radioactive substances originating from the power plants were found in the samples collected from the marine environment of both Finnish nuclear power plants. The terrestrial environment samples showed mainly fallout originating from the Chernobyl disaster. The quantities of the radioactive substances correspond to those observed in the environment of the plants in recent years and follow the longer-term downward trend, which is influenced by the development in the control of power plant releases. The radionuclides observed do not fundamentally deviate from the nuclides, originating from the power plants, observed in the marine environment in the previous years. In addition, the same nuclides were found in the marine environment as were reported by the power plants to have been released into the environment.

The quantities of radioactive substances detected in the environment were so small that they are insignificant in terms of the radiation exposure of the environment or people. No radioactive substances originating from the power plants were detected in the measurements of inhabitants of the area surrounding the power plants. The calculated radiation dose of the most exposed individual in the vicinity of both the Loviisa and Olkiluoto nuclear facilities in 2022 was less than 1% of the limit of 0.1 millisieverts set in the Nuclear Energy Decree (161/1988) (Häikiö, 2023).

The Cs-137 concentration observed in the particle samples collected from outdoor air during the annual outages is equivalent to the concentration of Cs-137 found in samples collected elsewhere in Finland, originating mainly from the fallout of the Chernobyl disaster. The quantities of Cs-137 and Sr-90 found in the terrestrial environment samples do not differ significantly from corresponding samples collected elsewhere in Finland, and the differences in the concentrations of Cs-137 in the different samples between the plant sites can be explained by the regional differences in the fallout of the Chernobyl disaster. Moreover, the quantities of Cs-137 and Sr-90 found in the samples do not differ from those found in the terrestrial environment samples of the vicinity of the power plants in the previous years. The C-14 concentrations of samples collected in the surroundings of the plants correspond to the concentrations of the reference samples collected elsewhere in Finland. No other radionuclides, possibly originating from the power plants, were detected in the terrestrial environment samples collected by STUK in 2022.

The Cs-137 concentrations observed in the terrestrial environment samples examined by the licensees correspond to those observed by STUK as part of its own monitoring. Small amounts of radionuclides originating from the power plants were detected in sludge from the wastewater treatment plant of the Loviisa power plant area and landfill run-off at Olkiluoto. The Cs-137 concentrations detected by the licensees in the terrestrial environment samples are equivalent to the concentrations of Cs-137 found in environmental samples elsewhere in Finland, originating mainly from the fallout of the Chernobyl disaster.

The analysis results of the seawater samples taken by the licensees corresponded to the results of the samples taken by STUK, except for a single seawater sample from Olkiluoto, whose higher tritium concentration was explained by the fact that sampling took place at the same time as the discharge of the plant’s process waters.

The findings of the environmental monitoring of the nuclear facilities carried out by STUK correspond to the findings of the environmental monitoring carried out by the licensees.

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9 Annexes

Annex 1 The radionuclides most commonly detected in the environment of nuclear power plants

Annex 2 Minimum requirements for a nuclear power plant's programme of environmental radiation surveillance, implemented by the licensee (Guide YVL C.7)

Annex 3 Collection schedule of STUK's monitoring samples

Annex 4 Results of periphyton sample monitoring measurements

ANNEX 1
The radionuclides most commonly detected in the environment of nuclear power plants

Nuclide	Half-life	Most common source in environmental samples	Occurrence in environmental monitoring
Tritium H-3	12.2 years	Power plant releases and nuclear weapons tests of the 1950s and 1960s	Water samples (terrestrial and marine environment)
Be-7 beryllium	53 days	Generated in the stratosphere as a result of cosmic radiation and in power plants (especially OL3) due to the activation of lithium in the primary circuit.	At OL3, the chemistry of the primary circuit is based on lithium, whose activation produces Be-7. Can be seen in water releases if the purification system is not working properly.
C-14 carbon	5,700 years	Cosmic (occurring in nature) or from power plants	C-14 from a power plant in gaseous form (CO_2 or CH_4), may end up in plants through photosynthesis (in case of a CO_2 release).
K-40 potassium	1.248×10^9 years	Naturally occurring radioactive substance	
Cr-51 chrome	27.7 years	Power plant releases	Air and maritime environment
Mn-54 manganese	312 days	Power plant releases	Air and maritime environment
Co-58, Co-60 cobalt	70 days 5.3 years	Power plant releases	Air and maritime environment
Sr-89, Sr-90 strontium	51 days 28.8 years	Power plant releases. Sr-90 in environmental samples also from nuclear weapons testing in the 1950s and 1960s	In maritime and terrestrial environment
Ru-103 Ru-106 ruthenium	39 days 372 days	Releases from a power plant or other nuclear facility	In air samples
Ag-110m silver	250 days	Power plant releases	Air and maritime environment
Sb-124 antimony	60 days	Power plant releases	Air and maritime environment
I-131 iodine	8 days	Power plant releases, also used in nuclear medicine at hospitals	May sometimes be detected in the monitoring of air and maritime environment samples, also separately screened from milk (never discovered). Also detected in sludge samples of water treatment plants, where iodine ends up mainly as a result of medicinal use.

ANNEX 1

THE RADIONUCLIDES MOST COMMONLY DETECTED IN THE ENVIRONMENT OF NUCLEAR POWER PLANTS

Cs-134, Cs-137 caesium	2.1 a 30 a	Cs-137 in environmental samples mainly from the Chernobyl fallout, Cs-134 a shorter-lived fission product and from power plant releases	Terrestrial and maritime environment
Ce-141 Ce-144 cerium	33 days 284 days	Power plant releases	Air and maritime environment
Pu-238, Pu-239 Pu-240 plutonium	87.7 years 24,110 years 6,561 years	Small concentrations detected in environmental monitoring, from nuclear weapons testing in the 1950s and the 1960s	In sediments and in sinking matter

ANNEX 2
Minimum requirements for a nuclear power plant's programme of environmental radiation surveillance, implemented by the licensee (Guide YVL C.7)

Control target	Number of monitoring instruments or samples and measurement or sampling sites	Collection frequency (number/period)	Analysis and frequency
B01. External radiation	External radiation dose rate measuring stations in the site area (or its vicinity) and outside of it at a distance of approx. 5 km from the power plant	—	Continuous measurement and recording
B02. External radiation	10–20 dosimeter stations evenly spread in the key directions at 1–10 km from the power plant	Continuous collection; dosimeters replaced four times a year	Gamma dose 4 times a year
B03. Radioactive substances in the form of airborne particles and iodine in the air	4–5 air sample collectors 1–10 km from the power plant	Continuous collection; filters replaced twice a month, except from the closest collector once a week during annual maintenance	Gamma emitters twice a month (once a week)
B04. Atmospheric deposition	3–5 rainwater collectors 1–10 km from the plant	Continuous collection; replacement from the closest collector once a month and from the others four times a year	Gamma emitters and ^3H from the closest collector once a month; other gamma emitters and ^3H four times a year.
B05. Indicator organisms in the terrestrial environment	A minimum of one indicator species that enriches radionuclides	1–2 times a year	Gamma emitters 1–2 times a year
B06. Garden products	1–10 km from the power plant; a minimum of 1 species	1–2 times a year	Gamma emitters 1–2 times a year
B07. Domestic water	From the power plant	4 times a year	Gamma emitters and ^3H 4 times per year
B08. Seawater or lake water depending on plant site	From at least one location near the discharge opening	2–4 times a year	Gamma emitters and ^3H from the closest point 4 times a year
B09. Special areas	If necessary, special areas in the environment of the nuclear power plant that may be significant in terms of radiation exposure to the environment, biota or humans may be selected as control targets. Special areas may include, for example, landfill runoff from the site area, water from the wastewater treatment plant and products grown or farmed near the nuclear facility (such as when residual heat from a power plant is utilised in the production of foodstuffs).		

ANNEX 3
Collection schedule of STUK's monitoring samples

January	February	March	April	May	June	July	August	September	October	November	December
Loviisa											
Sinking matter, 4 collection periods, 6 pcs/period, composite annual sample Pu											
	Fry 1 pc		Fry 1 pc		Needles spruce, γ + C-14		Supplementary air				
		Seawater 1 pc	Seawater 5 pcs		Grazing grass			Bottom sediment 5–6 pcs			
			Household water 1 pc				Mushrooms 4 species, γ			Seawater 5 pcs	
			Bladder wrack 5 pcs, γ			Soil 3–5 points every other year, Sr-90			Household water 1 pc, comm.		
	Sludge			Mesidothea entomon 1 pc		Fern, γ		Seawater 4 pcs			
					Reindeer lichen, γ		Bladder wrack 5 pcs				
				Periphyton, 1 point – 5 pcs samples							
					Grazing grass			Groundwater 1 per year, γ			
							Haircap moss 1 pc				
							Sludge	2 cereals/power plant, Sr-90 in wheat			
							Root vegetable 1 per year, γ				
				Fish 7 pcs							
				Ref. pike							
							Spiked water milfoil		Meat 1 pc, γ		
Milk 4 pcs/week, γ 1 x month, Sr-90 in the composite sample of the second and third quarter, I-131 during the annual outage plant shutdown.											

COLLECTION SCHEDULE OF STUK'S MONITORING SAMPLES

<table>
<tr><th colspan="2">January</th><th colspan="2">February</th><th colspan="2">March</th><th colspan="2">April</th><th colspan="2">May</th><th colspan="2">June</th><th colspan="2">July</th><th colspan="2">August</th><th colspan="2">September</th><th colspan="2">October</th><th colspan="2">November</th><th colspan="2">December</th></tr>
<tr><td colspan="24">Olkiluoto</td></tr>
<tr><td colspan="24">Sinking matter, 4 collection periods, 6 pcs/period, composite annual sample Pu</td></tr>
<tr><td colspan="2"></td><td colspan="2">Sludge 1 pc</td><td colspan="2">Seawater 1 pc</td><td colspan="2"></td><td colspan="2">Sludge 1 pc</td><td colspan="6">Spruce needles, γ + C-14</td><td colspan="2">Haircap moss 1</td><td colspan="2">Meat 1 pc, γ</td><td colspan="4"></td></tr>
<tr><td colspan="6"></td><td colspan="4">Bottom sediment 5–6 pcs</td><td colspan="4">Grazing grass</td><td colspan="6">Mushrooms 4 species, γ</td><td colspan="4"></td></tr>
<tr><td colspan="8"></td><td colspan="2">Seawater 6 pcs</td><td colspan="2"></td><td colspan="2">Fern, γ</td><td colspan="2"></td><td colspan="2">Seawater 1 pc</td><td colspan="2">Groundwater 1</td><td colspan="3">Seawater 6 pcs</td><td></td></tr>
<tr><td colspan="6"></td><td colspan="4">Household water comm. 1 pc</td><td colspan="2"></td><td colspan="6">Soil 3–5 points every other year, Sr-90</td><td colspan="4">Household water comm. 1 pc</td><td colspan="2"></td></tr>
<tr><td colspan="6"></td><td colspan="4">Bladder wrack 7 pcs</td><td colspan="3">Reindeer lichen, γ</td><td colspan="2"></td><td colspan="2">Bladder wrack 7</td><td colspan="7"></td></tr>
<tr><td colspan="8"></td><td colspan="2">Suppl. air</td><td colspan="3"></td><td colspan="4">2 pcs clams</td><td colspan="7"></td></tr>
<tr><td colspan="8"></td><td colspan="14">Periphyton 1 point, 5 pcs samples</td><td colspan="2"></td></tr>
<tr><td colspan="8"></td><td colspan="14">Fish 7 pcs or more</td><td colspan="2"></td></tr>
<tr><td colspan="24">Milk 4 pcs/week, γ 1 x month, Sr-90 in the composite sample of the second and third quarter, I-131 during the annual outage plant shutdown</td></tr>
<tr><td colspan="10"></td><td colspan="4">Grazing grass</td><td colspan="2"></td><td colspan="4">Root vegetable 1 per year, γ</td><td colspan="4"></td></tr>
<tr><td colspan="14"></td><td colspan="4">Spiked water milfoil</td><td colspan="4">2 cereals/power plant, Sr- 90 in</td><td colspan="2"></td></tr>
<tr><td colspan="13"></td><td colspan="4">Clam 2 pcs</td><td colspan="7"></td></tr>
<tr><td colspan="9"></td><td colspan="9">Ref. pike</td><td colspan="6"></td></tr>
</table>

Collection schedule plan of STUK's monitoring samples.

ANNEX 4
Results of periphyton sample monitoring measurements

Table 24. Results of the Loviisa periphyton sample monitoring measurements in 2022.

Collection period	Be-7	2σ	K-40	2σ	Co-58	2σ	Co-60	2σ	Nb-95	2σ	Zr-95	2σ	Ag-110m	2σ	Te-123m	2σ	Sb-124	2σ	Cs-137	2σ	Hf-181	2σ
18.11.21-27.04.22	770	10%	400	15%	< 1.0		0.9	43%	< 2.1		< 1.8		2.1	27%	< 0.4		< 1.1		60	10%	< 1.9	
27.04.22-19.05.22	140	10%	640	14%	< 1.0		< 1.0		< 1.3		< 2.0		< 1.1		< 0.6		< 1.0		50	7%	< 1.3	
19.05.22-10.06.22	230	7%	700	10%	< 0.6		< 0.7		< 0.7		< 1.0		1.0	36%	< 0.3		< 0.7		39	7%	< 0.8	
10.06.22-01.07.22	250	9%	670	11%	< 1.4		< 1.4		< 1.6		< 2.5		2.0	26%	< 0.6		< 1.3		76	10%	< 1.5	
01.07.22-14.07.22	420	9%	500	13%	< 0.8		0.9	42%	< 0.9		< 1.3		< 1.0		< 0.4		< 0.8		77	7%	< 0.9	
14.07.22-27.07.22	320	9%	380	11%	< 0.9		< 1.1		< 1.1		< 1.7		< 1.2		< 0.5		< 1.0		31	10%	< 1.2	
27.07.22-24.08.22	220	13%	430	22%	1.2	39%	1.7	33%	19	14%	9.4	16%	12	18%	0.4	40%	1.8	22%	29	13%	< 0.9	
24.08.22-06.10.22	320	8%	490	11%	< 1.1		57	9%	4.2	26%	< 1.9		12	16%	0.7	31%	5.6	15%	92	7%	2.0	17%
06.10.22-17.11.22	740	8%	510	12%	< 1.0		1.1	33%	< 1.6		< 1.8		< 1.3		< 0.8		< 1.3		105	9%	< 1.5	

Table 25. Results of the Olkiluoto periphyton sample monitoring measurements in 2022.

Collection period	Be-7	2σ	K-40	2σ	Mn-54	2σ	Co-58	2σ	Co-60	2σ	Cs-137	2σ
21.4.-3.6.2022	230	8%	670	10%	1.1	30%	< 0.8		4.4	10%	93	7%
3.6.-28.6.2022	46	12%	690	11%	< 0.7		< 0.8		1.8	26%	40	7%
28.6.-20.7.2022	166	8%	610	11%	< 0.4		1.5	18%	1.0	15%	94	7%
20.7.-16.8.2022	290	9%	650	13%	< 0.4		0.7	19%	0.9	24%	69	7%
16.8.-15.9.2022	290	9%	900	11%	< 1.1		< 1.2		7.9	16%	36	10%
15.9.-21.10.2022	810	8%	560	15%	< 1.1		< 1.7		7.7	12%	86	7%