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Monitoring of radioactivity in the environment of Finnish nuclear power plants

Annual report 2020

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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 2020. STUK's environmental monitoring and measurement 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 external 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 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 will perform independent regulatory control in the environment of the nuclear facility during the operation of the nuclear facility by taking and analysing samples from the environment of the nuclear facility to a necessary extent. With regard to arranging the environmental monitoring of nuclear facilities, also the IAEA has issued a recommendation Environmental and Source Monitoring for Purposes of Radiation Protection (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. 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 to 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 ventilation stacks of the power plants. Liquid radioactive substances generated at the nuclear power plant are purified by filtration and delaying 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 2020, the most significant abnormal disturbance situation was the reactor scram (I isolation) at the OL2 plant on 10 December due to the high level of activity of the main steam pipes. The increase in activity was the result of the entry into the reactor of a substance dissolved in the filter of the reactor water clean-up system. Releases are

[1] Licence holder shall refer in this report to the holder of a licence entitling to the use of nuclear energy.

monitored by process and release measurements made inside the plant and by monitoring the environmental radiation level and the presence of radioactive substances in the environmental samples. Measurements are used to ensure that the releases do not exceed the set limit values.

In 2020, the radioactive discharges from the power plants were small in relation to the set release limits (Fortum, 2021; TVO, 2021). 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 0.0002% of their respective release limits in 2020. The release of tritium (H-3) into the sea was approximately 11% and the release of fission and activation products into the sea was approximately 0.02% of their respective release limits. At Olkiluoto, the release of noble gases into the atmosphere was 0.01% and the release of iodine (at Olkiluoto, the release limit was set for I-131) was 0.12% of their respective release limits. The release of tritium into the sea was less than 10% and the release of fission and activation products into the sea was approximately 0.15% 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. 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 entitling to 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, household 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, 2021; TVO, 2021). 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 abnormal disturbances. Environmental radiation monitoring is targeted at the plant environment and the surrounding population.

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, household 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.

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. 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. Photo: STUK.

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, household 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 and spruce needles (new annual growth), are collected once a year. 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 household 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.

Household water samples are collected from the household 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 household 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.

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

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, bottom fauna, fish, bottom sediment and sinking matter are collected from the marine environment. The sampling points for the marine environment are shown in Figures 3 and 4.

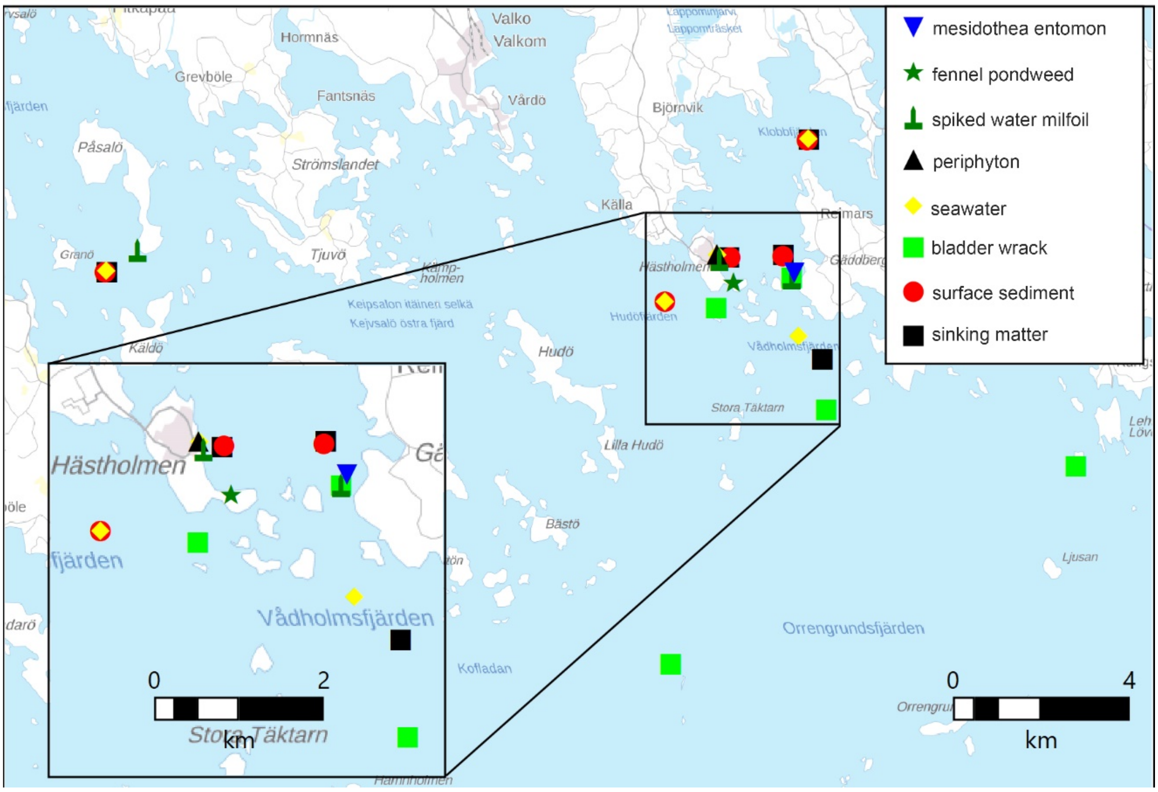

Figure 3. Sampling points in the marine environment of Loviisa. The map includes data from the Background map series 04/2020 of the National Land Survey of Finland.

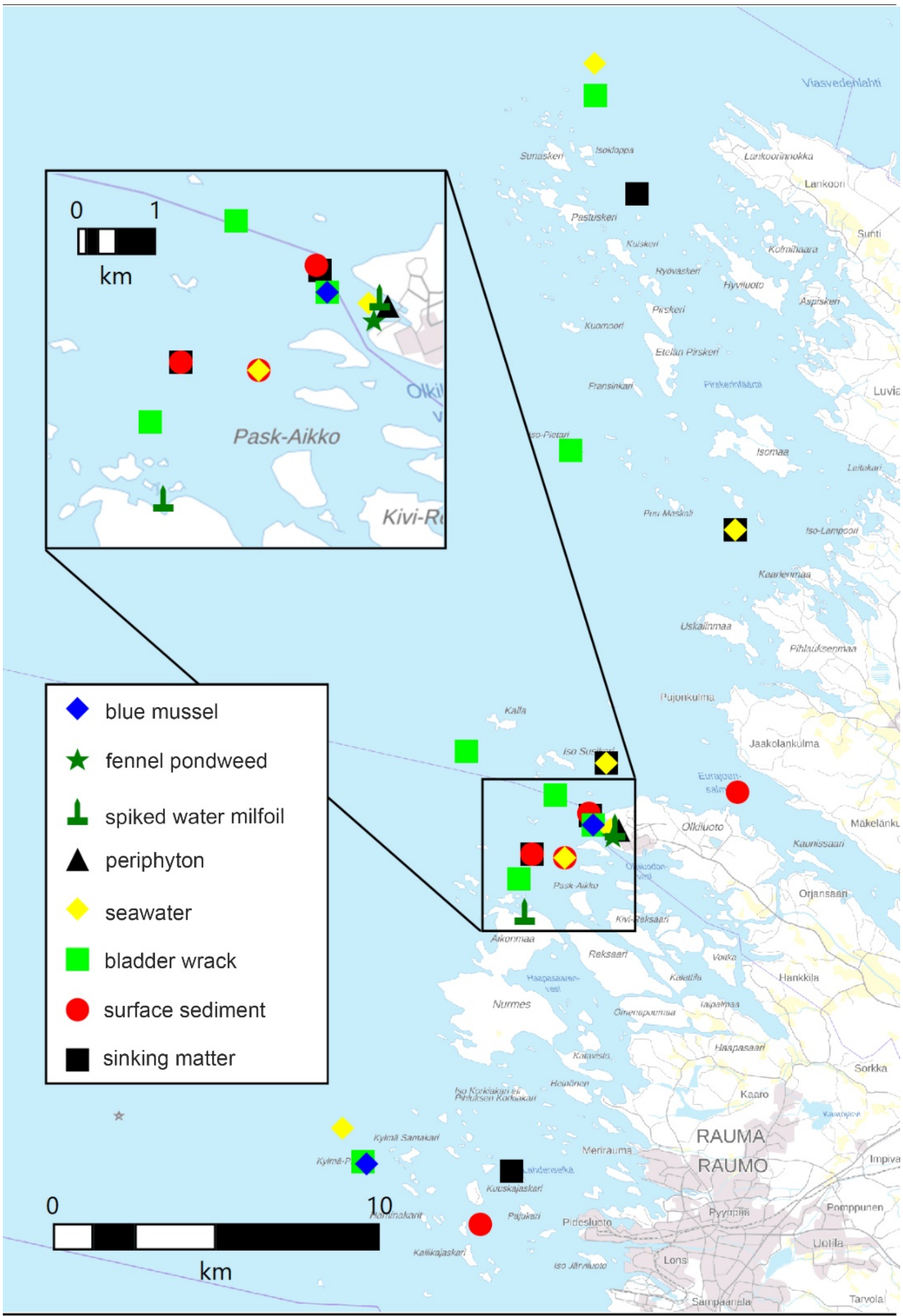

Figure 4. Sampling points in the marine environment of Olkiluoto. The map includes data from the Background map series 03/2021 of the National Land Survey of Finland.

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 plants with submerged leaves. 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 (Figure 5).

The collection of aquatic plants with submerged leaves includes spiked water milfoil and fennel pondweed. 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. In autumn 2020, a sample meeting the sampling criteria could no longer be collected from the point closest to the power plant, so the bladder wrack sample was replaced with a sample of spiked water milfoil. You can still find spiked water milfoil on the dismantling side of the plant. Periphyton is collected also 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 5. Sampling of bladder wrack by means of scuba diving, with the Olkiluoto power plant in the background (above). Bladder wrack (below). Photos: STUK.

The bottom fauna sample type includes blue mussel or mesidothea entomon, depending on availability. The samples are collected from one sampling point once a year (Figure 6). The fishing of 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 7)). 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 6. A bottom set pot for catching mesidothea entomon (on the left) and mesidothea entomon (on the right). Photos: STUK.

Figure 7. A collector of sinking matter. Photo: STUK.

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. In 2020, due to the COVID-19 pandemic, no persons over 70 years of age were invited to the measurements and the measurements were exceptionally carried out in late autumn. Normally, the aim is to carry out the measurements during the annual outages of the plants.

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 would have 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 Environmental Radiation Surveillance and Emergency Preparedness department of STUK. Milk, crops, 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 Environmental Radiation Surveillance 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 in Helsinki for analysis. If necessary, the samples are cleaned to only contain the targeted 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 the milk samples to prevent contamination. The milk samples are evaporated under the heat lamps and burnt. The iodine content (I-131) of milk is determined from a separate sample by ion exchange. The samples to be dried (lichen, moss, needles, ferns, mushrooms, grazing grass berries, game, crops, root vegetables, sludge, fish, bottom 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, the 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 determined from all samples, for example 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 analyses are used to analyse the alpha- and beta-active substances (H-3, Sr-89, Sr-90 and Pu-238, Pu-239 and Pu-240) of the samples. 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 solid samples are dissolved. Strontium is separated from the sample by an extraction chromatography method and Sr-90 is measured from the sample with a liquid scintillation spectrometer or, if both Sr-89 and Sr-90 are determined, the samples are measured with a proportional counter. Strontium chemical recovery determination is done by 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 and, 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 and, 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 household 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 activity concentration of Sr-89 remained below the limit of determination for all samples from which it was determined. The limits of determination of Sr-89 are separately compiled for the different sample types in Annex 3. The calculated activity concentrations of the radionuclides correspond to the average of the collection period and, therefore, the activity concentrations do not accurately reflect the activity concentrations of short-term releases that are temporarily higher. In addition, the average result does not correspond to the actual activity concentration if the half-life of the detected radio isotope is short relative to the collection period or if the release occurred at the beginning or at the end of the collection period. The uncertainty of the results is given with an accuracy of 2 σ (95% confidence interval).

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

Monitoring item	Gamma	Sr-90	Sr-89	C-14	H-3	Pu-238, Pu-239, Pu-240
External air	x					
Atmospheric deposition (annual sample)		x				
Soil	x	x				
Reindeer lichen	x					
Haircap moss	x					
Needles	x			x		
Ferns	x					
Mushrooms	x					
Berries	x					
Game	x					
Milk	x	x				
Grazing grass	x			x		
Crops	x	x	x			
Root vegetable	x					
Household water	x	x			x	
Groundwater	x					
Sludge	x					
Seawater	x	x	x		x	
Fry	x					
Periphyton	x					
Bladder wrack	x	x	x			x
Aquatic plants	x					
Bottom fauna	x	x	x			
Fish	x	x	x			
Surface sediment	x	x				x
Sinking matter	x					x
Inhabitants of the surroundings	x					

6 Results of environmental monitoring

A total of 467 samples were collected and analysed in the terrestrial and marine environment of the Olkiluoto power plant during 2020. 163 of the samples were STUK's monitoring samples and the rest were part of the licensee's own monitoring programme. A total of 493 samples of the terrestrial and marine environment of the Loviisa power plant were examined during 2020. Of these, 146 were STUK's regulatory monitoring 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 monitoring measurements of the 2020 samples are given in Tables 2–22 and in Annex 5. The results of the licensees' own measurements are discussed in the text. All radionuclides present in the result tables do not 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, forming usually 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. Typical background concentration of Cs-137 in external 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, 2020). 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 External air and atmospheric deposition

Continuous monitoring of radioactive substances in external air is the responsibility of the licensee. STUK carries out air sampling supplementing the licensee's measurements in conjunction with the annual outages at the plant sites (Table 2). The Cs-137 activity concentration of air samples was low.

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

Collection site	Collection period (ddmmyy)	Co-60 µBq/m³	I-131 µBq/m³	Uncertainty 2σ	Cs-137 µBq/m³	Uncertainty 2σ
Loviisa	10.8.20-14.8.20	< 1.0	< 1.0		0.84	61%
Loviisa	28.9.20-2.10.20	< 0.73	0.93	21%	1.65	22%
Olkiluoto	25.5.20-29.5.20	< 1.3	< 1.5		< 1.0	

In the licensee's own air measurements, Co-60 originating from the Loviisa power plant was detected in two air samples in the first quarter and in one air sample in the second quarter. No radionuclides originating from the power plant were detected at Olkiluoto.

The collection and monitoring of atmospheric deposition samples belong also to the monitoring programme of the licensees. The licensee's programme determines gamma-active radionuclides and H-3 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 of the atmospheric deposition samples of the whole year varied between 0.26 and 3.6 Bq/m^2, while the tritium concentration was less than 2 Bq/l. At Olkiluoto, the corresponding range was 0.11–0.28 Bq/m^2, while the tritium concentration was 2 Bq/l or less. No other nuclides originating from the power plants were detected. 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 0.02 and 0.08 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, 2020).

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

Site	Collection period (ddmmyy)	Sr-90 Bq/m²	2 σ
Loviisa	31.12.2019 - 31.12.2020	0.06	11%
	31.12.2019 - 31.12.2020	0.02	16%
Olkiluoto	27.12.2019 - 23.12.2020	0.08	10%

6.2 Terrestrial environment

No nuclides originating from the power plants were detected in terrestrial environment samples (Table 4). The Cs-137 concentrations in the terrestrial environment samples varied between different samples. Moss and lichen collect effectively radionuclides of their environment and these plants can show in some places 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 licensee collected lichen, moss, pine needle and fern samples from the environment of Olkiluoto. In these samples collected by the licensee, only natural nuclides and Cs-137 were detected, the concentration of Cs-137 varying between 87 and 510 Bq/kg. The activity concentrations of the samples correspond to the activity concentrations measured in the samples of STUK's monitoring programme. In the surroundings of the Loviisa power plant, the licensee collected a sample of ferns, which showed no nuclides originating from the power plant.

Table 4. Monitoring measurement results of the lichen, moss, needle and fern samples in 2020.

Site	Collection date (ddmmyy)	Be-7 Bq/kg	2σ	Cs-137 Bq/kg	2σ	C-14 Bq/kg	2σ	Sr-90 Bq/kg	2σ
Spruce needles									
Loviisa	5.6.20	< 5.6		410	10%	120	5%		
Olkiluoto	12.6.20	6.2	21%	120	10%	130	5%		
Reference Mäntyharju	21.6.20	11	17%	25	11%	120	5%	4.1	9.0%
Reindeer lichen									
Loviisa	11.8.20	170	12%	250	10%				
Olkiluoto	24.8.20	180	12%	87	10%				
Reference Mustio	2.7.20	170	12%	29	10%				
Haircap moss									
Loviisa	11.8.20	330	10%	2,030	10%			2.8	9.2%
Olkiluoto	5.8.20	360	8.0%	73	7.8%			1.7	9.5%
Reference Kimola	5.10.20	760	9.3%	240	9.2%				
Fern									
Loviisa	11.8.20	50	9.2%	2,300	7.6%				
Olkiluoto	25.8.20	230	12%	510	10%				
Reference Mustio	2.7.20	80	15%	220	13%				

The Cs-137 activity concentrations of mushroom samples collected in the vicinity of the Loviisa and Olkiluoto power plants varied between 51 and 490 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 obtained from local hunters had low activity concentrations of less than 40 Bq/kg per fresh weight.

Table 5. Monitoring measurement results of the mushroom, berry and game samples in 2020.

Site	Collection date (ddmmyy)	Species	Cs-137 Bq/kg FW	2σ
Mushrooms				
Loviisa	29.9.20	woolly milk cap	430	6%
	29.9.20	velvet bolete	490	12%
	30.9.20	slippery jack	79	11%
	29.9.20	trumpet chanterelle	270	13%
Olkiluoto	7.8.20	cep	51	12%
	25.8.20	chanterelle	61	11%
	22.9.20	rufous milk cap	72	7%
	22.9.20	wood hedgehog	190	12%
Berries				
Loviisa	11.8.20	bilberry	20	13%
	29.9.20	lingonberry	38	16%
Olkiluoto	27.8.20	raspberry	0.68	13%
Game				
Loviisa	3.11.20	elk	25	11%
	3.11.20	white-tailed deer	20	23%
Olkiluoto	21.11.20	elk	20	6.8%
	29.11.20	white-tailed deer	33	16%

The Cs-137 activity concentrations of milk samples varied between 0.04 and 0.75 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 the Loviisa sample and 0.03 Bq/l in the Olkiluoto sample. The activity concentrations are well in line with the activity concentrations of the national environmental monitoring of milk samples, which were between 0.11 and 1.4 Bq/l for Cs-137 and between 0.02 and 0.03 Bq/l for Sr-90 in 2019 (Mattila and Inkinen, 2020). Figures 8 and 9 show the activity concentration of Cs-137 in milk samples of the environmental monitoring programmes of the nuclear power plants in 2010– 2020. Every other 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 0.007–0.022 Bq/l).

In the monitoring programme, the monitoring measurements of the terrestrial environment agricultural products (crops and potato) and grazing grass showed no radionuclides originating from the power plants (Table 7). The Cs-137 activity concentration of the samples was low. No Sr-89 was detected in wheat. The Sr-90 activity concentration of crop samples was 0.04 Bq/kg in Loviisa and 0.22 Bq/kg in Olkiluoto. The C-14 content of grazing grass was 108 Bq/kg in Loviisa, 117 Bq/kg in Olkiluoto and 116 Bq/kg in the reference sample (Kimola). No radionuclides originating from the power plants were detected in the apple sample from the surroundings of Loviisa or in the lettuce sample from the surroundings of Olkiluoto in the monitoring programmes of the licensees.

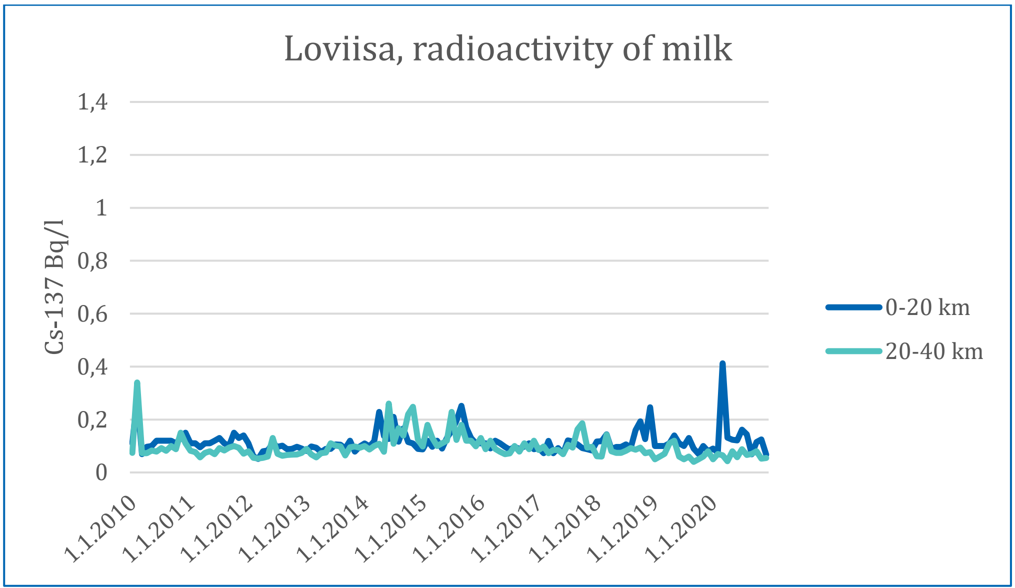

Figure 8. The Cs-137 concentration (Bq/l) of the milk samples supplied by dairies in the surroundings of the Loviisa power plant (distance of the farms from the plant 0–20 km or 20–40 km) in 2010–2020.

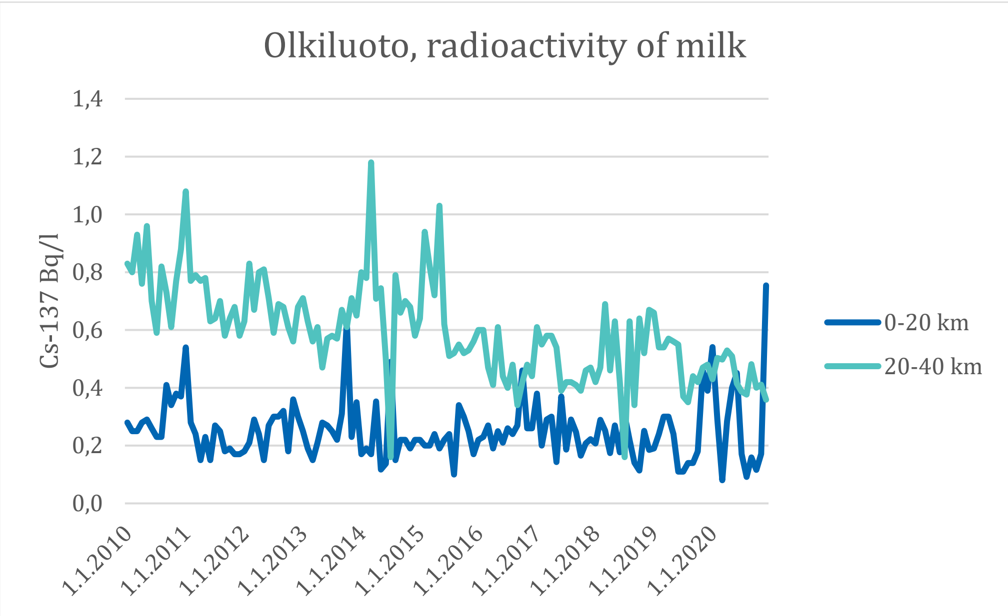

Figure 9. The Cs-137 concentration (Bq/l) of the milk samples supplied by dairies in the surroundings of the Olkiluoto power plant (distance of the farms from the plant 0–20 km or 20–40 km) in 2010–2020.

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 2020.

		0–20 km				**20–40 km**			
Locality	**Collection period (ddmmyy)**	**K-40 Bq/l**	**2σ**	**Cs-137 Bq/l**	**2σ**	**K-40 Bq/l**	**2σ**	**Cs-137 Bq/l**	**2σ**
Loviisa	5.1.20-26.1.20	49	15%	0.09	17%	48	18%	0.05	20%
	2.2.20-23.2.20	50	15%	0.08	14%	57	16%	0.07	21%
	1.3.20-29.3.20	47	11%	0.41	11%	51	17%	0.06	16%
	05.4.20-26.4.20	48	17%	0.13	13%	50	14%	0.04	23%
	3.5.20-31.5.20	52	17%	0.12	14%	51	11%	0.08	14%
	7.6.20-28.6.20	52	16%	0.12	17%	53	16%	0.06	19%
	5.7.20-26.7.20	48	15%	0.16	13%	47	27%	0.09	15%
	2.8.20-30.8.20	49	12%	0.14	15%	47	11%	0.07	15%
	6.9.20-27.9.20	47	11%	0.07	14%	47	18%	0.07	16%
	4.10.20-25.10.20	49	17%	0.11	13%	49	13%	0.08	14%
	1.11.20-29.11.20	46	15%	0.12	15%	49	15%	0.05	24%
	6.12.20-27.12.20	50	16%	0.07	24%	48	15%	0.05	23%
Olkiluoto	5.1.20-26.1.20	50	12%	0.54	14%	45	18%	0.43	13%
	2.2.20-23.2.20	47	15%	0.29	12%	49	15%	0.50	11%
	1.3.20-29.3.20	54	19%	0.08	15%	52	15%	0.50	15%
	5.4.20-26.4.20	52	18%	0.28	17%	49	15%	0.53	11%
	3.5.20-31.5.20	53	19%	0.40	11%	54	12%	0.51	14%
	7.6.20-28.6.20	52	16%	0.45%	15%	53	15%	0.41	14%
	5.7.20-26.7.20	47	15%	0.17	11%	55	15%	0.39	15%

	2.8.20-30.8.20	50	12%	0.09	16%	52	14%	0.38	10%
	6.9.20-27.9.20	48	14%	0.16	16%	48	15%	0.48	11%
	4.10.20-25.10.20	49	15%	0.12	18%	51	17%	0.40	12%
	1.11.20-29.11.20	52	16%	0.17	16%	48	15%	0.41	11%
	6.12.20-27.12.20	50	14%	0.75	9%	47	15%	0.36	11%

Table 7. Monitoring measurement results of the grazing grass, crops and root vegetable samples in 2020.

Site	Collection date (ddmmyy)	Species	K-40 Bq/kg	uncertainty 2σ	Cs-137 Bq/kg	uncertainty 2σ
Grazing grass						
Loviisa	13.8.20	Grazing grass	740	13%	0.57	31%
Olkiluoto	2.6.20	Grazing grass	660	12%	0.95	20%
Reference, Kimola	17.8.20	Grazing grass	940	15%	1.5	24%
Crops						
Loviisa	08.10.20	Wheat	140	15%	0.12	41%
	08.10.20	Oat	110	17%	0.70	16%
Olkiluoto	20.10.20	Wheat	140	15%	0.55	13%
	20.10.20	Oat	110	17%	0.46	21%
Reference, Kimola	5.10.20	Wheat	98	17%	0.3	18%
	5.10.20	Oat	100	13%	0.3	21%
Root vegetable						
Loviisa	08.10.20	Potato	155	14%	0.14	25%
Olkiluoto	20.10.20	Potato	146	17%	< 0.06	

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

Table 8. Monitoring measurement results of the household water of the cities of Rauma and Loviisa in 2020.

Site	Collection date (ddmmyy)	H-3 Bq/l	2σ	Sr-90 Bq/m^3	2σ	Cs-137 Bq/m^3	2σ
Loviisa	15.5.20	< 0.97				< 0.30	
	4.12.20	< 1.02				< 0.49	
	15.5.20-7.12.20*			< 0.07			
Loviisa power plant	28.2.20-1.12.20*			2.8	9%		
Rauma	27.5.20	< 0.97				1.6	18%
	20.10.20	1.03	63%			2.2	20%
	27.5.20-20.10.20*			6.5	9%		
Olkiluoto power plant	21.1.20-23.9.20*			3.5	9%		

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

No artificial radionuclides were found in either of the groundwater samples taken in the surroundings of Loviisa and Olkiluoto. Two sludge samples were taken at the Vårdö wastewater treatment plant near Loviisa, one in February and the other during the annual outage in August. No nuclides originating from the power plants were detected in these samples. 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, Cr-51, Co-58, Co-60, Ag-110m, Nb-95, Zr-95, Te-123m, Sb-124 and Hf-181. Of these, Nb-95, Zr-95 and Hf-181 are detected less frequently, while other nuclides are detected more frequently in sludge samples (Fortum, 2021). In Olkiluoto, the sludge sample was taken during annual outage in May at UPM Rauma's wastewater treatment plant. I-131, a common nuclide used in radionuclide therapy in hospitals, was detected in the sample (21 Bq/kg per dry weight of the sample). It is likely that the I-131 originates from a patient who has received radionuclide therapy.

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. On 10 October 2020, a severe abnormal disturbance occurred at the Olkiluoto nuclear power plant Unit 2, leading to a reactor scram. The potential impact of the disturbance on the environment was monitored the following week by taking an additional seawater and spiked water milfoil sample near the discharge opening of the plant.

Tables 9 and 10 show the monitoring measurement results of the seawater samples in 2020. The results are presented in an 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 one sample. 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 household 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.

In the longer time series (Figures 10 and 11), 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 1.05 and 5.95 Bq/l in Loviisa and between 2.2 and 2.3 Bq/l in Olkiluoto. The analysis results of the seawater samples taken by the licensees corresponded to the results of the samples taken by STUK.

Table 9. Monitoring measurement results of the Loviisa seawater samples in 2020.

Site	Collection date (ddmmyy)	H-3 Bq/l	uncertainty 2σ	Sr-90 Bq/m^3	uncertainty 2σ	Cs-137 Bq/m^3	uncertainty 2σ
Halkokari 02	11.2.20	2.8	26%	5.6	10%	14	13%
	7.4.20	2.7	26%	5.5	10%	12	14%
	11.8.20	1.6	41%	6.2	10%	12	13%
	12.11.20	2.1	33%	5.3	13%	12	15%
Klobbfjärden 1	17.3.20	6.4	16%			11	15%
	12.11.20	3.3	24%			12	17%
Vådholmsfjärden 4	18.3.20	16	12%			14	17%
	12.11.20	1.8	38%			12	17%
Hudöfjärden 8	18.3.20	1.4	47%			13	17%
	11.11.20	1.4	47%			13	12%
Påsalöfjärden R1	18.3.20	< 0.98		5.1	10%	9	15%
	11.11.20	1.1	59%	6.0	13%	10	15%

Table 10. Monitoring measurement results of the Olkiluoto seawater samples in 2020.

Site	Collection date (ddmmyy)	H-3 Bq/l	uncertainty 2σ	Sr-90 Bq/m³	uncertainty 2σ	Cs-137 Bq/m³	uncertainty 2σ
Iso Kaalonperä 13	27.2.20	9.9	13%	6.0	10%	19	12%
	16.4.20	< 0.98		6.0	10%	< 0.52	
	6.8.20	20	11%	6.6	10%	23	12%
	20.11.20	1.2	55%	5.5	14%	20	13%
	17.12.20*	3.9	21%			19	13%
Liponluoto 2	2.4.20	1.1	55%			17	13%
	20.11.20	1.1	59%			20	13%
Rääpinkivet 3	2.4.20	< 0.98				17	13%
	18.11.20	1.0	63%			19	16%
Santakari 15	2.4.20	< 0.98				19	13%
	18.11.20	< 1.0				19	11%
Kylmäpihlaja 17	6.5.20	< 0.97				20	16%
	17.11.20	< 1.0				18	13%
Viikari 16	2.4.20	< 0.98		5.7	10%	19	16%
	18.11.20	< 1.0		5.1	13%	20	13%

*Extra sampling after abnormal disturbance situation at Olkiluoto unit 2

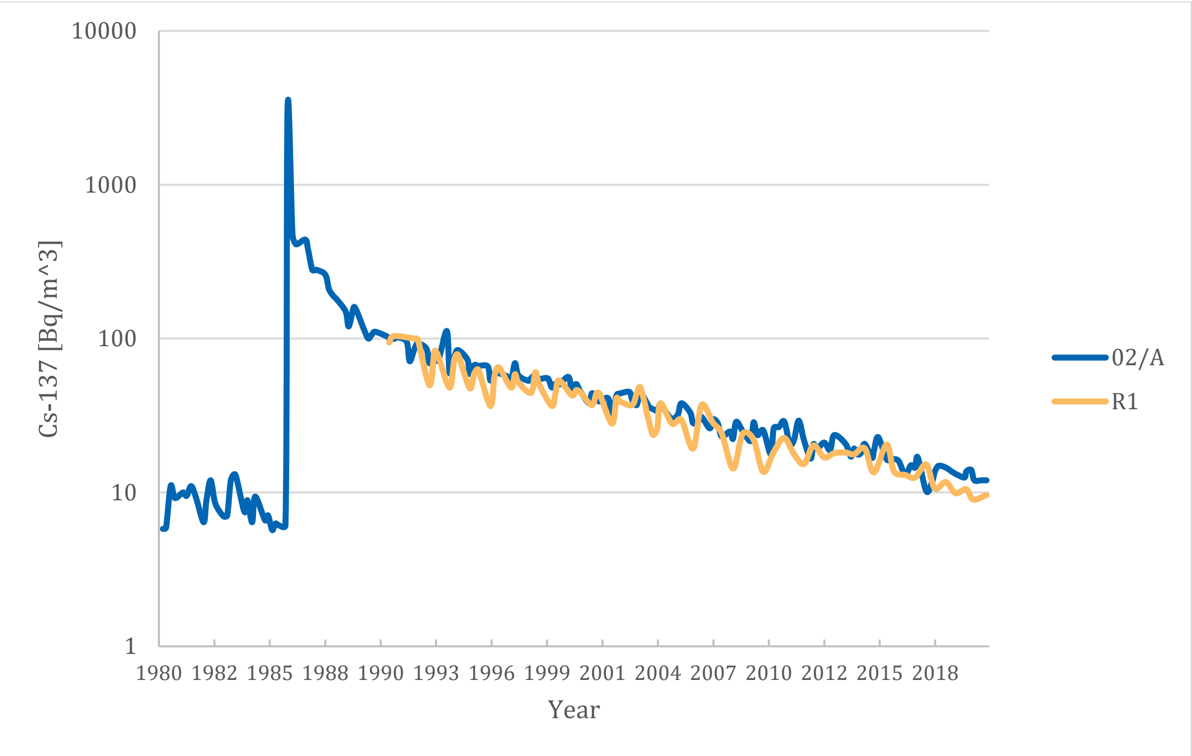

Figure 10. The Cs-137 activity concentration in seawater at the nearest (02/A, blue) and furthest (R1, yellow) sampling point of the Loviisa power plant in 1980–2020 presented on a logarithmic scale.

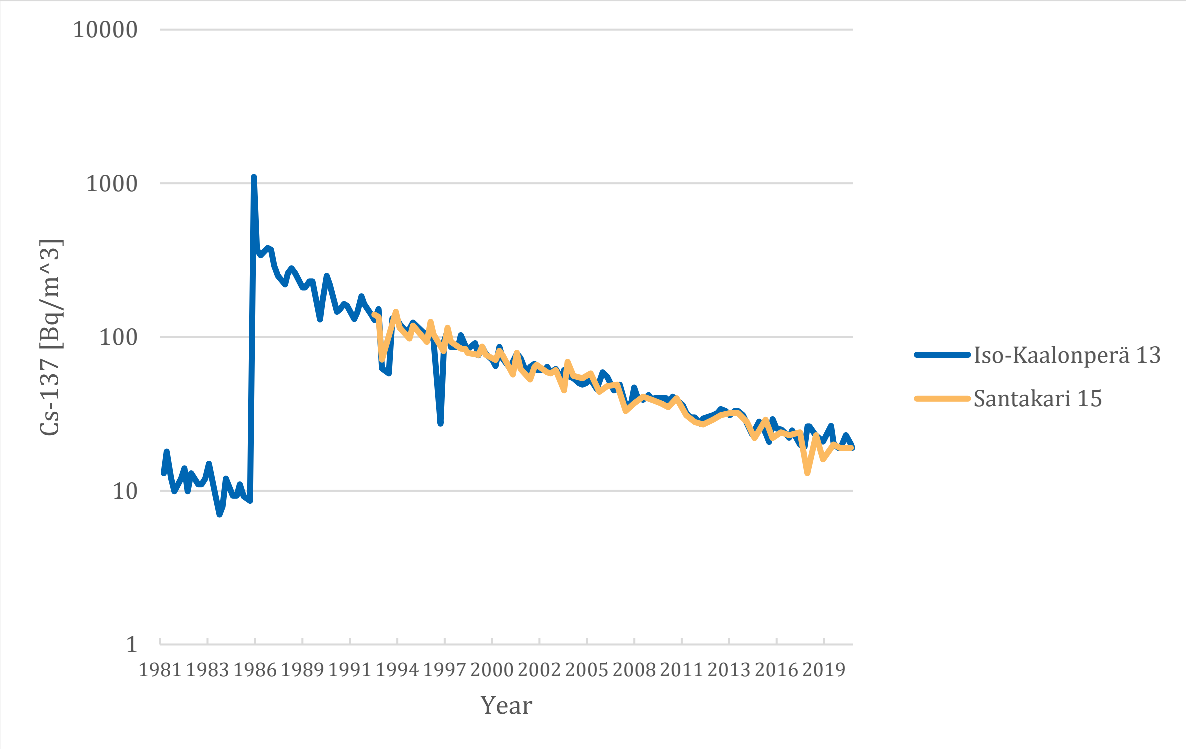

Figure 11. The Cs-137 activity concentration in seawater at the nearest (Iso-Kaalonperä 13, blue) and furthest (Santakari 15, yellow) sampling point of the Olkiluoto power plant in 1981–2020 presented on a logarithmic scale.

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, perch, pike and roach) varied between 1.9 and 11 Bq/kg (per fresh weight, Table 11). 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, 2020). 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 bottom fauna samples (mesidothea entomon and blue mussel) were low (Table 12). The mesidothea entomon 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 organism.

Table 11. Monitoring measurement results of the fish samples from the marine environment of Loviisa and Olkiluoto in 2020.

Sample type	Site	Collection period (ddmmyy)	Cs-137 Bq/kg	Uncertainty 2σ	Sr-90 Bq/kg	Uncertainty 2σ
Baltic herring	Loviisa 0–10 km	30.7.20	3.5	12%	0.035	19%
	Olkiluoto 0–10 km	6.5.20-7.5.20	3.1	17%	0.030	22%
Perch	Loviisa 0–2 km	3.6.20-4.6.20	8.3	11%	0.015	24%
	Loviisa 2–10 km	4.6.20-28.7.20	7.5	12%		
	Olkiluoto 0–3 km	7.5.20-10.6.20	11	18%	0.006	43%
	Olkiluoto 3–10 km	8.7.20-8.7.20	11	17%		
	Reference	4.6.20 – 28.7.20	6.2	13%		
Pike	Loviisa 0–2 km	19.5.20-31.7.20	5.9	12%		
	Loviisa 2–10 km	16.6.20-29.7.20	6.3	11%		
	Olkiluoto 0–3 km	7.5.20	6.8	9%		
	Olkiluoto 3–10 km	6.8.20	7.6	9%		
	Reference	29.7.20	6.2	23%		
Bream	Loviisa 0–2 km	13.5.20	2.0	9%		
	Loviisa 2–10 km	16.6.20-28.7.20	1.9	18%		
	Olkiluoto 0–3 km	7.5.20	2.8	17%		
	Olkiluoto 3–10 km	27.5.20	2.2	10%		
Fry sample	Loviisa, Smoltti	8.6.20	0.14	23%		

Table 12. Monitoring measurement results of the bottom fauna collected from the marine environment of Loviisa and Olkiluoto in 2020.

Sample type	Site	Collection period (ddmmyy)	Sr-90 Bq/kg	2σ	Ag-110m Bq/kg	2σ	Cs-137 Bq/kg	2σ
Mesidothea entomon	Hästholmsfjärden 3	6.4.20-9.4.20	8.9	10%	1.3	20%	6.8	14%
Blue mussel	Iso Kaalonperä	4.8.20	7.3	13%	< 0.4		0.50	38%
Blue mussel	Reference, Kylmäpihlaja	5.8.20	not determined		< 0.4		0.62	41%

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. Figures 12 and 13 show the annual averages of the activity concentrations of some of the most significant nuclides originating from the power plant in bladder wrack samples collected nearest the power plant. 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 14 and 15 show the link between the activity concentration of Co-60 in the bladder wrack samples and the Co-60 discharges from the power plant 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 releases 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.

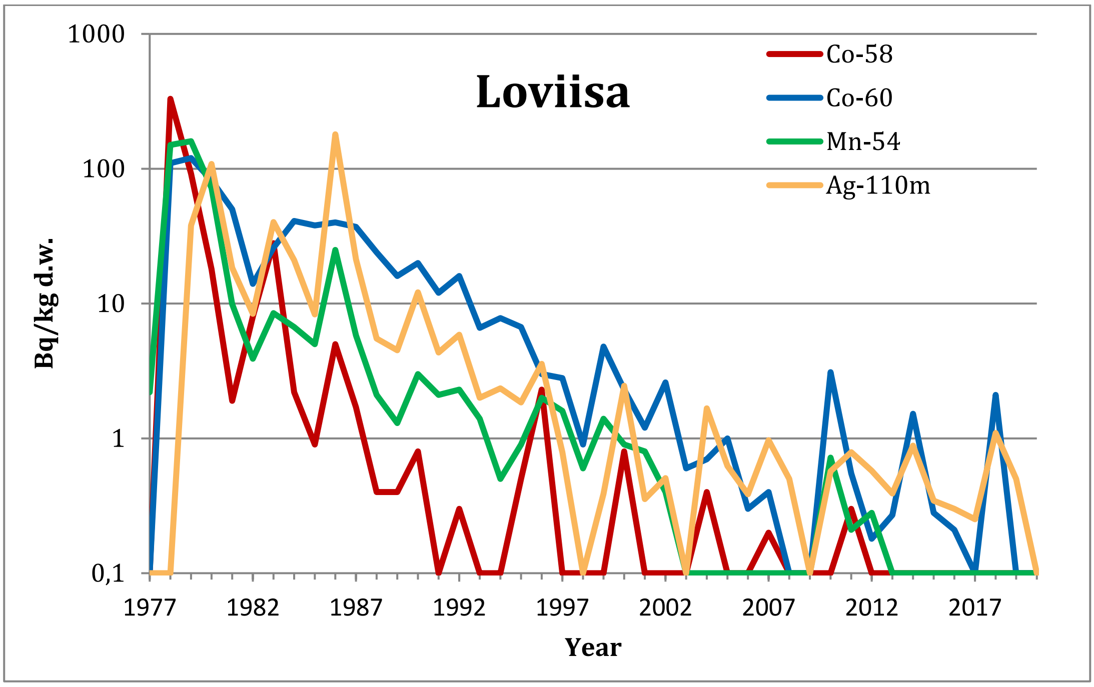

Figure 12. Averages of the activity concentrations of the most significant radionuclides originating from the power plant in bladder wrack (Bq/kg per dry weight) at the nearest sampling point of the Loviisa power plant in 1977–2020 on a logarithmic scale.

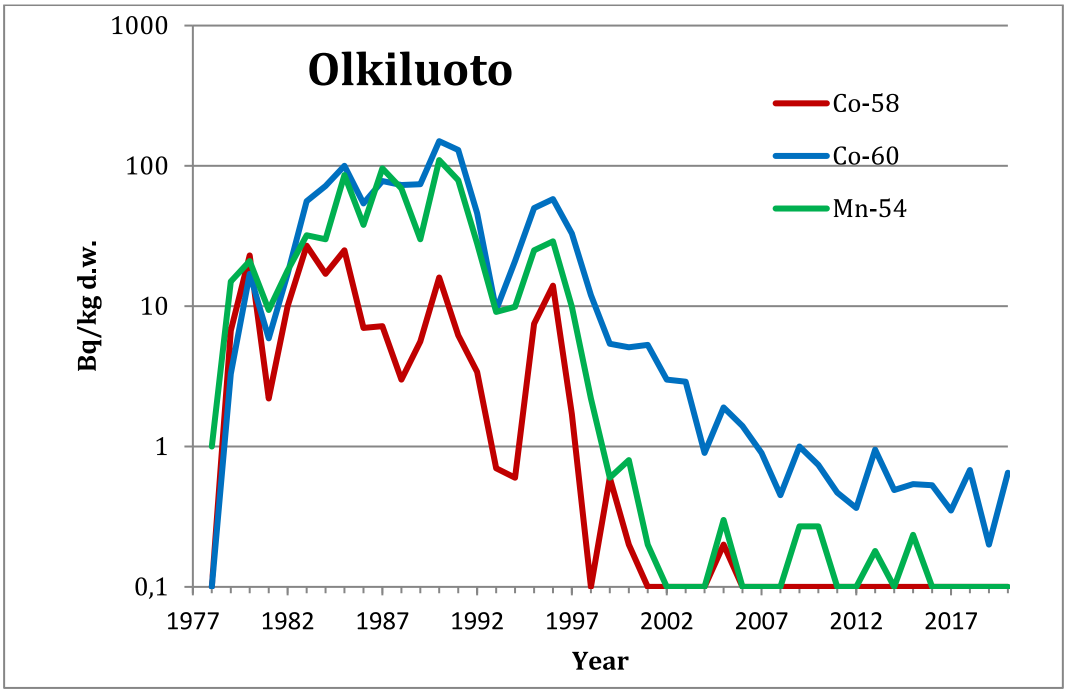

Figure 13. Averages of the activity concentrations of the most significant radionuclides originating from the power plant in bladder wrack (Bq/kg per dry weight) at the nearest sampling point of the Olkiluoto power plant in 1977–2020 on a logarithmic scale.

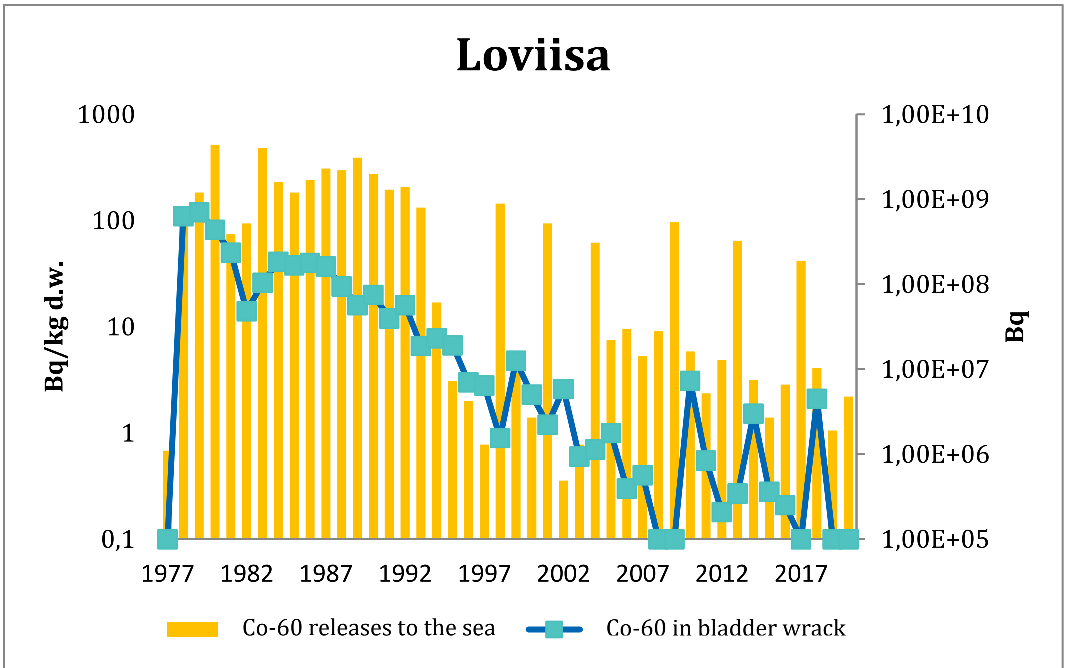

Figure 14. The Co-60 releases into the sea and the average of the Co-60 activity concentration in the bladder wrack samples of the nearest sampling point of the Loviisa power plant in 1977–2020.

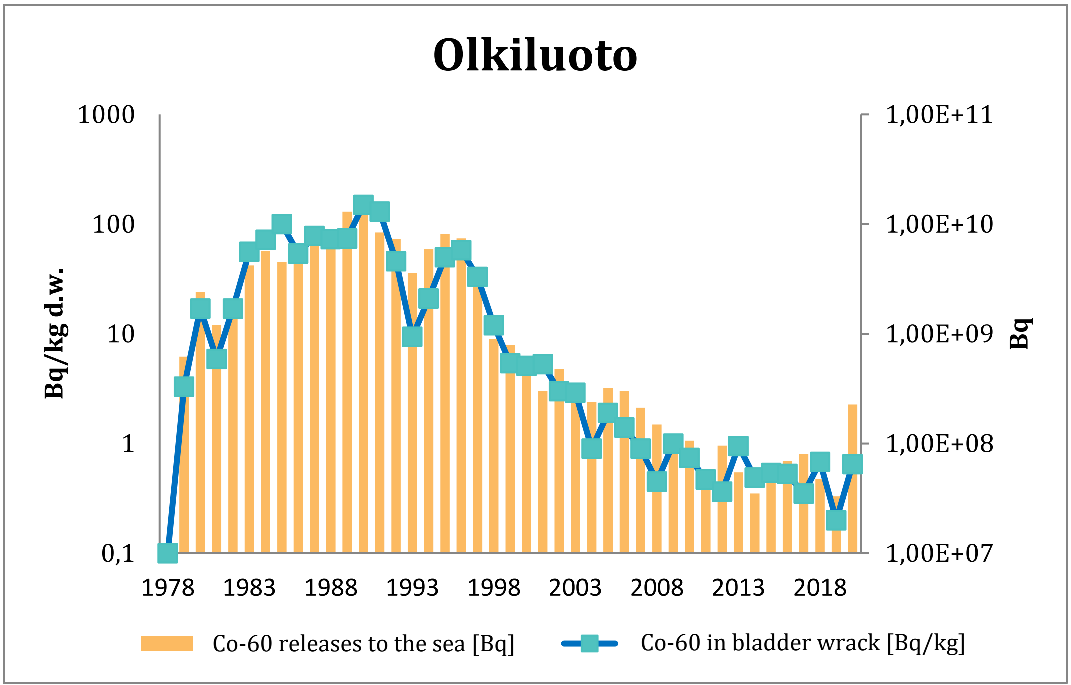

Figure 15. The Co-60 releases into the sea and the average of the Co-60 activity concentration in the bladder wrack samples of the nearest sampling point of the Olkiluoto power plant in 1977–2020.

The results of the periphyton samples are given in Annex 5. 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-60, Nb-95, Zr-95, Ag-110m, Te-123m, Sb-124 and Cs-137, and those of Olkiluoto were Mn-54, Co-58, Co-60, I-131, Cs-134, Cs-137, La-140 and Ce-141. In addition to periphyton samples, Co-60 was also detected in bladder wrack in Olkiluoto (Tables 13 and 14). No radionuclides originating from the power plants were detected in bladder wrack in Loviisa. The Cs-137 activity concentrations of bladder wrack varied between 7.9 and 16 Bq/kg. A second bladder wrack sample could not be obtained at the Björkholmen sampling point in Loviisa due to the lack of plant life; a spiked water milfoil sample was used as a replacement. 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 ones 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 aquatic plants with submerged leaves (Tables 15 and 16). Some nuclides originating from the power plants were detected in the additional spiked water milfoil sample taken due to the abnormal disturbance situation at Olkiluoto, but the activity concentrations did not differ significantly from the concentrations of the sample taken during annual outage. Ag-110m was detected in one of the samples of aquatic plants with submerged leaves (spiked water milfoil) collected from the discharge area of the Loviisa power plants, and Mn-54, Co-58, Co-60, Sb-125 and Ce-141 were detected in the samples of aquatic plants with submerged leaves (spiked water milfoil and fennel pondweed) collected from the discharge area of Olkiluoto. The Cs-137 activity concentrations of the spiked water milfoil samples were between 3.5 and 34 Bq/kg. The reference samples of aquatic plants with submerged leaves were collected further away from the discharge opening but still in the vicinity of the power plant (Tallholmen in Loviisa and

Aikonmaa 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 13. Radionuclides found in the bladder wrack samples collected in the marine environment of Loviisa in 2020.

Sampling point	Collection date (ddmmyy)	Cs-137 Bq/kg	2σ	Sr-90 Bq/kg	2σ
Stenörarna	13.5.20	14	16%		
	28.7.20	13	11%		
Björkholmen B1	13.5.20	16	13%	6.7	11%
Lilla Djupberget C	12.5.20	11	10%		
	28.7.20	14	11%		
Boistö D	12.5.20	12	11%		
	28.7.20	15	16%		
Storskarven E	12.5.20	11	18%	4.7	10%
	28.7.20	10	17%		

Uncertainty at a precision of 2σ

Table 14. Radionuclides found in the bladder wrack samples collected in the marine environment of Olkiluoto in 2020.

Site	Collection date (ddmmyy)	Co-60 Bq/kg	2σ	Cs-137 Bq/kg	2σ	Sr-90 Bq/kg	2σ
Iso Kaalonperä 9	7.5.20	< 0.43		15	18%	5.2	10%
	4.8.20	1.3	13%	13	12%		
Kalliopöllä B	7.5.20	< 0.39		15	12%		
	4.8.20	0.90	17%	12	16%		
Reimarkrunni	6.5.20	0.41	49%	12	18%		
	5.8.20	2.0	18%	12	18%		
Iso-Siiliö D	8.5.20	< 0.31		8.3	12%		
	5.8.20	< 0.52		12	12%		
Iso-Pietari C	7.5.20	< 0.32		9.5	13%		
	4.8.20	< 0.4		13	12%		
Kylmäpihlaja 17	6.5.20	< 0.32		7.9	12%		
	5.8.20	< 0.21		7.6	11%		
Viikari 16	5.5.20	< 0.33		9.1	13%	4.5	10%
	4.8.20	< 0.27		13	18%		

Table 15. Radionuclides found in the samples of aquatic plants with submerged leaves collected in the marine environment of Loviisa in 2020.

Site	Species	Collection date (ddmmyy)	Ag-110m Bq/kg	2σ	Cs-137 Bq/kg	2σ
Halkokari	Spiked water milfoil	30.7.20	< 0.36		20	17%
Tallholmen (Reference)	Fennel pondweed	30.7.20	< 0.22		3.6	13%
Björkholmen B1*	Spiked water milfoil	12.8.20	3.7	19%	11	12%

*Replaces a bladder wrack sample

Table 16. Radionuclides found in the samples of aquatic plants with submerged leaves collected in the marine environment of Olkiluoto in 2020.

Site	Species	Collection date (ddmmyy)	Mn-54 Bq/kg	2σ	Co-58 Bq/kg	2σ	Co-60 Bq/kg	2σ	Sb-125 Bq/kg	2σ	Cs-137 Bq/kg	2σ	Ce-141 Bq/kg	2σ
Iso Kaalonperä	Spiked water milfoil	11.6.20	5.3	13%	< 0.4		36	7%	1.1	50%	30	11%	< 0.4	
Iso Kaalonperä	Fennel pondweed	6.8.20	0.41	38%	< 0.4		6.5	15%	< 0.8		3.5	18%	< 0.3	
Iso Kaalonperä	Spiked water milfoil	17.12.20*	4.3	15%	1.3	27%	20	12%	< 1.2		9.4	12%	0.7	29%
Aikonmaa (Reference)	Spiked water milfoil	6.8.20	< 0.4		< 0.4		< 0.4		< 1.0		34	17%	< 0.5	

*Extra sampling after abnormal disturbance situation at Olkiluoto unit 2

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 17 and 18). Co-58, Co-60, Nb-95, Ag-110m and Cs-137 were detected in Loviisa, and Co-60, Sb-125 and Cs-137 were detected in Olkiluoto. Cs-137 found in the sinking matter originates largely from the Chernobyl disaster. Table 19 presents the activity concentrations of the plutonium isotopes Pu-238 and Pu-239/240 detected in the bladder wrack samples and sinking matter. The plutonium originates from the global fallout from the atmospheric nuclear weapons tests.

Table 17. Radionuclides observed in the sinking matter samples collected from the marine environment of Loviisa in 2020.

Site	Collection period (ddmmyy)	Co-58 Bq/kg	2σ	Co-60 Bq/kg	2σ	Nb-95 Bq/kg	2σ	Ag-110m Bq/kg	2σ	Cs-137 Bq/kg	2σ
Hästholmsfjärden 5S	13.11.19-19.3.20	< 0.6		< 0.7		< 2.0		1.6	21%	300	12%
	19.3.20-4.6.20	< 0.8		< 0.7		< 1.6		< 0.9		260	13%
	4.6.20-2.9.20	< 1.3		1.2	33%	2.2	41%	24	13%	220	11%
	2.9.20-12.11.20	1.0	20%	1.1	32%	1.7	28%	7.5	15%	260	11%
Hästholmsfjärden 3	13.11.19-17.3.20	< 0.9		0.7	33%	< 1.6		1.9	34%	330	11%
	17.3.20-2.6.20	< 0.8		< 0.6		< 1.5		< 0.9		270	11%
	2.6.20-1.9.20	< 1.4		< 1.1		< 2.3		2.1	35%	210	15%
	1.9.20-10.11.20	< 0.7		1.0	39%	< 1.0		3.8	24%	220	10%

Klobbfjärden 1	13.11.19-19.3.20	< 0.6		< 0.4		< 1.2		< 0.8		320	11%
	19.3.20-2.6.20	< 0.6		< 0.5		< 0.9		< 0.8		340	13%
	2.6.20-2.9.20	< 0.7		< 0.6		< 1.4		2.4	14%	300	8%
	2.9.20-11.11.20	< 0.7		< 0.7		< 1.2		1.7	29%	340	13%
Vådholmsfjärden 4	12.11.19-18.3.20	< 1.3		< 0.8		< 2.3		< 1.0		330	11%
	18.3.20-3.6.20	< 1.0		< 0.7		< 1.7		< 1.0		260	18%
	3.6.20-1.9.20	< 0.8		< 0.7		< 1.5		< 0.8		290	11%
	1.9.20-10.11.20	< 0.6		< 0.6		< 1.1		< 0.8		230	17%
Påsalöfjärden R1	12.11.19-18.3.20	< 1.3		< 0.9		< 2.6		< 1.2		230	17%
	18.3.20-3.6.20	< 0.5		< 0.4		< 0.9		< 0.5		220	16%
	3.6.20-1.9.20	< 0.5		< 0.4		< 0.8		< 0.5		220	13%
	1.9.20-11.11.20	< 0.6		< 0.5		< 0.9		< 0.8		230	11%

Table 18. Radionuclides observed in the sinking matter samples collected from the marine environment of Olkiluoto in 2020.

Site	Collection period (ddmmyy)	Co-60 Bq/kg	2σ	Sb-125 Bq/kg	2σ	Cs-137 Bq/kg	2σ
Rääpinkivet 3	20.11.19-2.4.20	< 0.57		< 1.6		150	10%
	2.4.20-9.6.20	< 0.69		< 1.4		140	16%
	9.6.20-25.8.20	1.3	29%	< 1.8		120	10%
	25.8.20-17.11.20	0.86	28%	< 1.2		150	13%
Vähä Kivikkokari 12	21.11.19-30.3.20	< 0.67		2.1	23%	170	11%
	2.4.20-11.6.20	< 0.44		< 1.1		180	11%
	11.6.20-25.8.20	< 0.84		< 2.3		160	11%
	25.8.20-17.11.20	0.59	43%	< 1.5		150	17%
Kaalonperä 9	29.10.19-30.3.20	< 0.70		< 2.0		180	13%
	30.3.20-9.6.20	0.83	18%	< 1.8		130	11%
	9.6.20-25.8.20	2.2	30%	< 2.4		130	11%
	25.8.20-17.11.20	1.6	15%	< 1.1		150	10%
Santakari 15	20.11.19-2.4.20	< 0.68		< 1.7		190	13%
	2.4.20-10.6.20	< 0.79		< 2.1		160	11%
	10.6.20-26.8.20	< 1.21		< 2.5		140	7%
	26.8.20-18.11.20	< 0.69		< 1.6		180	13%
Kuuskajaskari 20	21.11.19-2.4.20	< 0.65		< 1.7		170	18%
	2.4.20-11.6.20	< 0.91		< 2.2		150	18%
	11.6.20-25.8.20	< 0.66		< 1.9		160	11%
	25.8.20-17.11.20	< 0.43		< 1.2		170	16%
Keskivedenkari 18	19.11.19-2.4.20	< 0.60		< 1.6		160	11%
	2.4.20-10.6.20	< 0.45		< 1.4		130	11%
	10.6.20-26.8.20	< 0.72		< 1.9		140	11%
	26.8.20-18.11.20	< 0.52		< 1.2		120	10%

Table 19. Activity concentrations of the plutonium isotopes Pu-238 and Pu-239/240 of the bladder wrack samples and sinking matter samples collected from the marine environment of Loviisa and Olkiluoto in 2020.

Site	Site	Sample type	Collection period (ddmmyy)	Pu-238 Bq/kg	2σ	Pu-239/240 Bq/kg	2σ
Loviisa	Storskarven E	Bladder wrack	12.5.20	< 0.012		0.035	53%
Olkiluoto	Iso Kaalonperä 9	Bladder wrack	7.5.20	< 0.017		0.048	57%
	Viikari 16	Bladder wrack	5.5.20	4.5	10%	< 0.011	
Loviisa	Hästholmsfjärden 5S	Sinking matter	13.11.19-12.11.20	0.049	37%	0.82	13%
	Påsalöfjärden R1	Sinking matter	12.11.19-11.11.20	< 0.018		0.31	14%
Olkiluoto	Rääpinkivet 3	Sinking matter	20.11.19-17.11.20	< 0.019		0.57	13%
	Keskivedenkari 18	Sinking matter	19.11.19-18.11.20	0.015	47%	0.49	13%

Radionuclides originating from the power plants were found in surface sediment in the marine environment of the power plants (Table 20). Co-60 (0.38–1.1 Bq/kg) and Ag-110m (0.56–1.4 Bq/kg) were found in Loviisa, and the Cs-137 concentration of sediment in the vicinity was between 280 and 340 Bq/kg. Co-60 (0.71–6.1 Bq/kg) was found at Olkiluoto, and the Cs-137 concentration of sediment in the vicinity was between 180 and 210 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 200–240 Bq/kg. Sediment shows small background concentrations of the Sr-90, Pu-238, Pu-239 and Pu-240 radionuclides originating from the global fallout from the atmospheric nuclear weapons tests. The activity concentrations of Sr-90, Pu-238, Pu-239 and Pu-240 in the environmental radiation monitoring programmes 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 20. Radioactive substances found in the marine environment sediment samples in 2020.

Site	Collection date (ddmmyy)	Co-60 Bq/kg	2σ	Sr-90 Bq/kg	2σ	Ag-110m Bq/kg	2σ	Cs-137 Bq/kg	2σ	Pu-238 Bq/kg	2σ	Pu-239/240 Bq/kg	2σ
Hästholmsfjärden 5, Loviisa	1.10.20	1.1	18%	0.82	14%	1.4	25%	310	7%	0.025	42%	0.91	12%
Hästholmsfjärden 3, Loviisa	1.10.20	0.70	36%	0.98	21%	0.56	26%	280	16%	0.024	63%	0.88	13%
Klobbfjärden 1, Loviisa	1.10.20	0.38	57%	1.5	19%	1.4	26%	330	10%	< 0.024		1.2	12%
Hudöfjärden 8, Loviisa	1.10.20	< 0.75		0.96	19%	< 0.86		340	13%	< 0.036		1.2	12%
Påsalöfjärden R1, Loviisa	1.10.20	< 0.49		0.27	27%	< 0.75		240	11%	0.012	59%	0.35	15%
Vähä Kivikkokari 12, Olkiluoto	23.6.20	0.71	17%	0.48	14%	< 0.56		190	13%	0.11	23%	0.80	13%

Olkiluoto 9, Olkiluoto	23.6.20	6.1	9%	0.80	12%	< 0.70		190	11%	0.024	44%	0.73	13%
Liponluoto 2, Olkiluoto	23.6.20	0.75	19%	0.55	15%	< 0.75		210	11%	0.026	65%	0.66	14%
Tankarit 4, Olkiluoto	24.6.20	1.2	14%	0.80	12%	< 0.61		180	11%	< 0.025		0.65	14%
Olkiluoto S8, Olkiluoto	25.6.20	< 0.55		2.0	10%	< 0.57		200	16%	< 0.025		0.89	13%

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.

7 Summary and conclusions

In 2020, small quantities of radioactive substances originating from the power plants were found in the environment of both Finnish nuclear power plants. Radioactive substances were detected in individual samples collected by the licensees from external air and in samples collected from the marine environment. The terrestrial environment samples showed mainly fallout originating from the Chernobyl disaster. The quantities of the radioactive substances correspond largely to those observed in the environment of the plants in the previous years and follow the longer-term downward trend, which is influenced by the development in the control of power plant releases. 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 was in 2020 less than 1% of the limit of 0.1 millisieverts set in the Nuclear Energy Decree (161/1988) (Marttila, 2021).

The Cs-137 concentration observed in the particle samples collected from external 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. Similarly, the quantity of Cs-137 found in the terrestrial environment samples does 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 across Finland. The same conclusion also applies to Sr-90 found in the terrestrial environment samples. 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 in 2020.

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. In the environment of both power plants, no radionuclides, other than Cs-137, possibly originating from the power plants were detected in the terrestrial environment samples examined by the licensees. The Cs-137 concentration observed in the samples is equivalent to the concentrations of Cs-137 found in environmental samples elsewhere in Finland, originating mainly from the fallout of the Chernobyl disaster.

In the vicinity of both power plants, small amounts of radionuclides originating from the power plants can be seen in the marine environment samples. The radionuclides observed do not fundamentally deviate from the nuclides, originating from the power plants, observed in the marine environment in the previous years. Radionuclides originating from the power plant were found in additional samples collected from the marine environment of Olkiluoto after the operational occurrence at the plant. The activity concentrations of the observed radionuclides did not significantly differ from the samples during the annual outage of the power plant.

Same nuclides were found in the environment of the nuclear facilities as were reported by the power plants to have been released into the environment. 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.

8 References

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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

Annex 3 Collection schedule of STUK’s monitoring samples

Annex 4 Sr-89 specified limits for various sample types (Bq/kg)

Annex 5 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
H-3 tritium	12.2 years	Plant emissions and 1950s and 1960s nuclear weapons tests	Water samples (land and marine environment)
Be-7 beryllium	53 days	Generated in the stratosphere as a result of cosmic radiation	
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 (if CO_2 emission).
K-40 potassium	1.248×10^9 years	Naturally occurring radioactive substance	
Cr-51 chrome	27.7 years	Power plant releases	Atmospheric and maritime environment
Mn-54 manganese	312 days	Power plant releases	Atmospheric and maritime environment
Co-58, Co-60, cobalt	70 days 5.3 years	Power plant releases	Atmospheric and maritime environment
Sr-89, Sr-90 strontium	51 days 28.8 years	Power plant releases. Sr-90 in environmental samples also from nuclear weapon testing in the 1950s and 1960s	In maritime and land 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	Atmospheric and maritime environment
Sb-124 antimony	60 days	Power plant releases	Atmospheric and maritime environment
I-131 iodine	8 days	Power plant releases, also in use in nuclear medicine at hospitals	May sometimes be detected in the monitoring of air and maritime environment samples, also separately inspected in milk (never discovered). Also detected in sludge samples of water treatment plants, where iodine ends up mainly as a result of medicinal use.
Cs-134, Cs-137 caesium	2.1 a 30 a	Cs-137 in environmental samples mainly from the Chernobyl fallout,	Land and maritime environment

		Cs-134 a shorter-lived fission product and from power plant releases	
Ce-141 Ce-144 cerium	33 days 284 days	Power plant releases	Atmospheric 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 weapon 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. 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. Household 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, living populations 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

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Week
Measurement or sample																											Measurement or sample
Terrestrial environment																											**Terrestrial environment**
External air																											External air
Soil (every other year)																											Soil
Reindeer lichen																											Reindeer lichen
Haircap moss																											Haircap moss
Spruce tip																											Spruce tip
Ferns																											Ferns
Products occurring in the wild (mushrooms, berries)	every year																										Products occurring in the wild and game
Grazing grass																											Grazing grass
Milk (0–20 km)																											Milk (0–20 km)
Milk (< 40 km)																											Milk (< 40 km)
Crops																											Crops
Root vegetable																											Root vegetable
Meat																											Meat
Household water, comm.																											Household water, comm.
Groundwater																											Groundwater
Sludge																											Sludge
Marine environment																											**Marine environment**
Seawater																											Seawater
Periphyton																											Periphyton
Bladder wrack																											Bladder wrack
Aquatic plants																											Aquatic plants
Bottom fauna																											Bottom fauna
Fish																											Fish
Sinking matter																											Sinking matter
Bottom sediment																											Bottom sediment
Fish farm																											Fish farm

Sampling schedule for the environmental radiation monitoring programme of the Loviisa power plant 2020 ->, July–December

	Jul				Aug					Sep				Oct				Nov					Dec				
Week	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	Week
Measurement or sample																											Measurement or sample
Terrestrial environment																											**Terrestrial environment**
External air																											External air
Soil (every other year)																											Soil
Reindeer lichen																											Reindeer lichen
Haircap moss																											Haircap moss
Spruce tip																											Spruce tip
Ferns																											Ferns
Products occurring in the wild (mushrooms, berries)																											Products occurring in the wild and game
Grazing grass																											Grazing grass
Milk (0–20 km)																											Milk (0–20 km)
Milk (< 40 km)																											Milk (< 40 km)
Crops																											Crops
Root vegetable																											Root vegetable
Meat																											Meat
Household water, comm.																											Household water, comm.
Groundwater																											Groundwater
Sludge																											Sludge
Marine																											**Marine**

ANNEX 3
COLLECTION SCHEDULE OF STUK'S MONITORING SAMPLES

environment																											**environment**
Seawater																											Seawater
Periphyton																											Periphyton
Bladder wrack																											Bladder wrack
Aquatic plants																											Aquatic plants
Bottom fauna																											Bottom fauna
Fish																											Fish
Sinking matter																											Sinking matter
Bottom sediment																											Bottom sediment
Fish farm																											Fish farm

Collection schedule of STUK's monitoring samples. The black bars indicate the sample-taking period of continuously operating collectors Grey colouring shows the time the samples are collected.

ANNEX 4
Sr-89 specified limits for various sample types (Bq/kg)

Sample type	Specified limit Bq/kg
Crops	< 0.4 Bq/kg
Seawater	<20 Bq/m^3
Bottom fauna	< 3.0 Bq/kg
Bladder wrack	< 20 Bq/kg

ANNEX 5
Results of periphyton sample monitoring measurements

Table 21. Results of Loviisa periphyton sample monitoring measurements in 2020.

Collection period (ddmmyy)	Be-7	2σ	K-40	2σ	Mn-54	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
14.11.19-19.03.20	1,400	11%	680	13%	< 1.3		< 1.7		< 1.4		< 3.0		< 3.0		1.7	28%	< 0.7		< 1.9		240	14%
13.03.20-08.04.20	450	12%	450	17%	< 0.6		< 0.7		< 0.8		< 0.9		< 1.1		< 1.1		< 0.3		< 0.7		130	11%
08.04.20-15.05.20	290	11%	870	16%	< 0.4		< 0.4		< 0.5		< 0.6		< 0.7		1.1	19%	< 0.2		< 0.4		94	11%
15.05.20-05.06.20	180	11%	780	11%	< 0.7		< 0.7		< 0.9		< 0.8		< 1.3		< 1.0		< 0.3		< 0.7		82	11%
05.06.20-17.06.20	370	13%	600	19%	< 0.8		< 0.7		< 1.1		< 0.9		< 1.4		< 1.1		< 0.4		< 0.8		92	13%
17.06.20-03.07.20	650	16%	570	22%	< 0.9		< 1.0		< 1.1		< 1.3		< 1.9		< 1.6		< 0.8		< 1.2		110	15%
03.07.20-31.07.20	200	18%	690	17%	< 0.3		< 0.3		< 0.4		< 0.4		< 0.6		< 0.4		< 0.2		< 0.3		20	16%
31.07.20-13.08.20	450	11%	490	16%	1.3	40%	4.3	18%	5.5	13%	4.0	19%	2.2	15%	140	14%	0.5	41%	3.8	17%	76	11%
13.08.20-02.09.20	500	12%	640	27%	< 0.9		1.2	29%	2.4	24%	< 1.3		< 1.9		26	16%	< 0.5		1.8	36%	66	12%
02.09.20-01.10.20	330	12%	440	17%	< 0.9		4.8	15%	6.9	11%	2.7	25%	< 1.2		26	16%	< 0.3		3.5	18%	70	11%
01.10.20-12.11.20	830	11%	770	13%	< 1.1		< 1.2		2.0	26%	< 1.5		< 2.0		5.9	20%	< 0.6		< 1.3		200	14%

Table 22. Results of Olkiluoto periphyton sample monitoring measurements in 2020.

Collection period (ddmmyy)	Be-7	2σ	K-40	2σ	Mn-54	2σ	Co-58	2σ	Co-60	2σ	I-131	2σ	Cs-134	2σ	Cs-137	2σ	La-140	2σ	Ce-141	2σ
27.02.20-16.04.20	360	12%	420	17%	< 0.7		< 0.9		< 0.8		< 3.4		< 0.7		69	11%	< 3.3		< 0.9	
16.04.20-08.05.20	190	13%	560	19%	< 0.7		< 0.7		1.3	18%	< 1.5		< 0.7		90	17%	< 2.0		< 0.7	
08.05.20-28.05.20	120	11%	520	15%	18	11%	1.9	17%	80	10%	5.5	23%	< 0.7		71	14%	1.9	31%	4.0	20%
28.05.20-11.06.20	190	16%	900	16%	3.9	18%	< 0.7		29	11%	< 1.6		0.7	24%	89	15%	< 1.2		< 1.0	
11.06.20-25.06.20	140	16%	630	16%	4.1	18%	< 0.8		41	10%	< 1.8		< 0.8		100	15%	< 1.4		< 1.0	
25.06.20-08.07.20	290	13%	680	9%	< 0.5		< 0.5		2.1	16%	< 1.1		< 0.5		130	13%	< 1.0		< 0.5	
07.07.20-06.08.20	210	11%	720	16%	< 0.6		< 0.6		3.4	13%	< 1.6		< 0.5		74	11%	< 1.6		< 0.5	
06.08.20-26.08.20	260	11%	540	16%	< 0.8		< 0.9		8.7	12%	< 2.1		< 0.9		64	11%	< 1.9		< 0.9	
26.08.20-24.09.20	210	12%	560	17%	2.1	26%	0.9	46%	5.4	13%	< 2.5		< 0.7		60	11%	< 2.2		< 0.8	
25.09.20-20.10.20	230	13%	430	19%	1.5	51%	< 1.2		2.0	28%	< 5.6		< 1.0		25	17%	< 6.2		< 1.3	