stuk

B

STUK-B 255/MAY 2020

Virtanen S., Vartti V-P., Turunen J., Mattila A.

Monitoring of radioactivity in the environment of Finnish nuclear power plants

Annual report 2019

Radiation and Nuclear Safety
Authority
P.O. Box 14
FI-00811 Helsinki
www.stuk.fi

Further information:
Sinikka Virtanen
sinikka.virtanen@stuk.fi
telephone +358 9 759 88 556

ISBN 978-952-309-462-8 (pdf)
ISSN 2243-1896

VIRTANEN Sinikka, VARTTI Vesa-Pekka, TURUNEN Jani, MATTILA Aleksi, Radiation monitoring of the environment of a nuclear power plant in Finland. Annual report 2019. STUK-B 255 Helsinki, 2020, 48 p.

KEYWORDS: Environmental monitoring, nuclear facility

Contents

Summary

This report describes the results of radiation monitoring carried out by the Radiation and Nuclear Safety Authority (STUK) in the environment of Fortum's nuclear power plants in Loviisa and Teollisuuden Voima's (TVO) nuclear power plants at Olkiluoto in 2019. STUK's monitoring complements the monitoring of the radiation levels and radioactive substances in the environment of the plants 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 analysis methods include gamma spectrometric and radiochemical analyses. 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 themselves correspond to the findings of STUK's environmental monitoring.

1 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 estimated 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 [1] for the radiological monitoring of the environment of a nuclear facility. 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.

2 Releases from nuclear power plants

During the operation of nuclear power plants, radioactive substances are generated, a very small proportion of which may end up in the environment during normal operation of the nuclear facility. 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. Releases are 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 2019, the radioactive discharges from the power plants were small in relation to the set release limits (Fortum, 2020; TVO, 2020). 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)

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

was approximately 0.0003% of their respective release limits in 2019. 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 0.01% of their respective release limits. At Olkiluoto, the release of noble gases into the atmosphere was 0.02% and the release of iodine (at Olkiluoto, the release limit was set for I-131) was 0.74% 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 0.04% 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. 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.

3 Environmental monitoring programme of the licensees

The holder of a licence entitling to the use of nuclear energy shall monitor the levels 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 monitoring the levels of radioactivity 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, 2020; TVO, 2020). 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 in this report where applicable.

4 Environmental monitoring programme 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. 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, 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.

4.1 Monitored pathways

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. The sampling methods are described in more detail in Section 5.1.

4.1.1 Outdoor air and atmospheric deposition

Sampling of outdoor air belongs mainly to the licensee's monitoring programme. STUK takes an outdoor air sample supplementing the licensee's measurements in conjunction with the annual outages at the plant sites. In addition, the Sr-90 concentration is determined from the annual composite sample of the atmospheric deposition samples collected by the licensees.

4.1.2 Terrestrial environment

The terrestrial environment samples include soil, reindeer lichen, haircap moss, needles, ferns, mushrooms, 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. The analysis of natural plants includes species identified as good enrichers of radioactive substances, such as moss, reindeer lichen, ferns and needles. Mushroom samples are also collected annually according to local availability.

By examining agricultural products and domestic water it is possible to assess the internal exposure of humans to radioactive substances via food. Milk samples are collected from dairies which receive milk from dairy farms in the vicinity of the power plant. Grazing grass samples are collected from the vicinity of the power plant during the growing season. The analysis of garden and agricultural products includes different cereals and root vegetables.

Domestic water samples are taken from the raw water or tap water from the power plants and waterworks of the neighbouring cities. The groundwater sample is taken from groundwater intake plants near the nuclear power plants. Sludge samples are collected before and once during the annual outage from the water treatment plants of the neighbouring cities.

4.1.3 Marine environment

Monitoring of marine samples helps to monitor the dispersion of power plant releases in the marine environment and their accumulation in marine environment flora and fauna. Marine environment samples include seawater, fry, periphyton, bladder wrack, aquatic plants with submerged leaves, benthic fauna, fish, bottom sediment and sinking matter.

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

The analysis on aquatic plants includes bladder wrack and plants with submerged leaves. These plants collect radionuclides from water and are therefore good release indicators. Bladder wrack samples are taken at several points several times a year. 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. Also periphyton is collected as algal samples. Periphyton refers to organisms attached to a solid surface in water, mainly algae. Collection continues throughout the growing season.

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. Collected fish samples include at least four different species, for example Baltic herring, pike, perch, roach or bream. There are two sampling areas for fish other than herring and one larger area for herring. 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. Fishing takes place once a year.

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 from several sampling points where continuous collection is carried out around the year. Bottom sediment samples are collected from several sampling points annually.

4.1.4 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 from both power plant locations 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 5 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 5–7 km of the nuclear power plant. The name and address information is based on an extract of the address register of the 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.

5 Monitoring methods

The Environmental Radiation Surveillance and Emergency Preparedness (VALO) department of STUK is a testing laboratory T167 accredited by the FINAS Finnish Accreditation Service. STUK's sampling and analysis methods (except for the C-14 analysis) are certified by FINAS and based on the ISO 17025:2017 laboratory standard. The method descriptions and instructions are documented in STUK's internal manuals which are subject to the accreditation. The C-14 analyses of the monitoring programme are carried out at the Laboratory of Chronology of the University of Helsinki. The sampling methods, the pre-treatment of samples and the analysis methods are briefly described in Sections 5.1 and 5.2.

5.1 Sampling methods

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

STUK collects outdoor air particle samples during the annual outages of the plants. The continuous collection of outdoor air particle samples is included in the monitoring programme carried out by licensees. The air samplers pump air through the fibreglass filter and the activated carbon cartridge. 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 collection and monitoring of atmospheric deposition samples belong to the monitoring programme of the licensees. Gamma-active radionuclides are determined from the atmospheric deposition samples collected by the licensees. STUK examines the activity concentration of Sr-90 from the whole year's composite atmospheric deposition samples as part of STUK's monitoring programme.

5.1.2 Terrestrial environment

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 1) and five 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. Haircap moss, ferns, spruce needles and reindeer lichen are collected once a year. Spruce tips 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.

Milk samples are collected from nearby dairies in containers supplied and labelled by STUK that contain a preservative. Milk comes from dairies in the vicinity of the power plant, the longest distances from the power plant being about 40 km. Sampling observes the general procedures for the food sampling of milk. The grazing grass samples are collected once during the growing season. Pastures have been selected 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.

Crop samples are supplied by local grain stores from grain farms located in the environment of the power plant 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 collected from the vicinity of the power plant once during the summer season. Four different species of mushroom are also collected annually from the vicinity of the power plants according to local availability.

Domestic water samples are collected from the domestic water of the cities of Loviisa and Rauma twice a year, in the spring and autumn. In addition, Sr-90 is determined from the plant's domestic water supplied by the licensees. The groundwater sample is collected from a groundwater intake plant near the power plants or directly from the groundwater pipeline. Sludge samples are collected from the nearest wastewater treatment plant of the power plant twice a year. In 2019, the sludge samples were taken only from the wastewater treatment plant near the Loviisa power plant. The collection of sludge samples from the vicinity of the Olkiluoto power plant will be included in the monitoring programme starting from 2020.

Figure 1. Slicing of a soil sample taken with a golf hole cutter. Photo: STUK.

5.1.3 Marine environment

The sampling points for the marine environment are shown in Figures 2 and 3. Marine samples are taken from surface water at several points. 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. The fish samples may be taken in any way that is generally used in fishing. As regards Loviisa, a fry sample received from a nearby fish farm is also examined. There is no fish farming activity near Olkiluoto.

The sinking matter is collected from several points into cylindrical collection tubes, which are anchored to the desired depth (Figure 4).

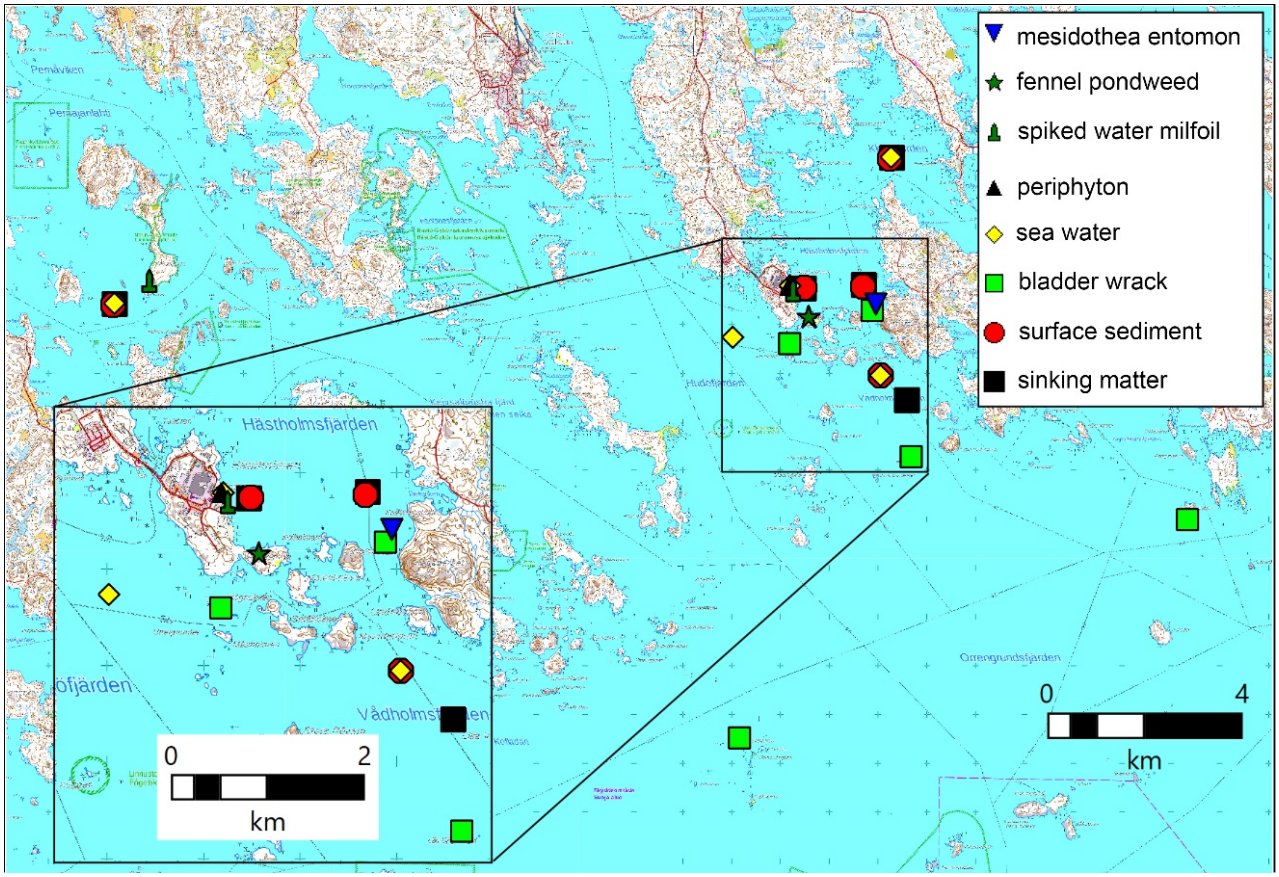


Figure 2. Sampling points in the marine environment of Loviisa. The map includes data from the Topographic Database 04/2016 of the National Land Survey of Finland.

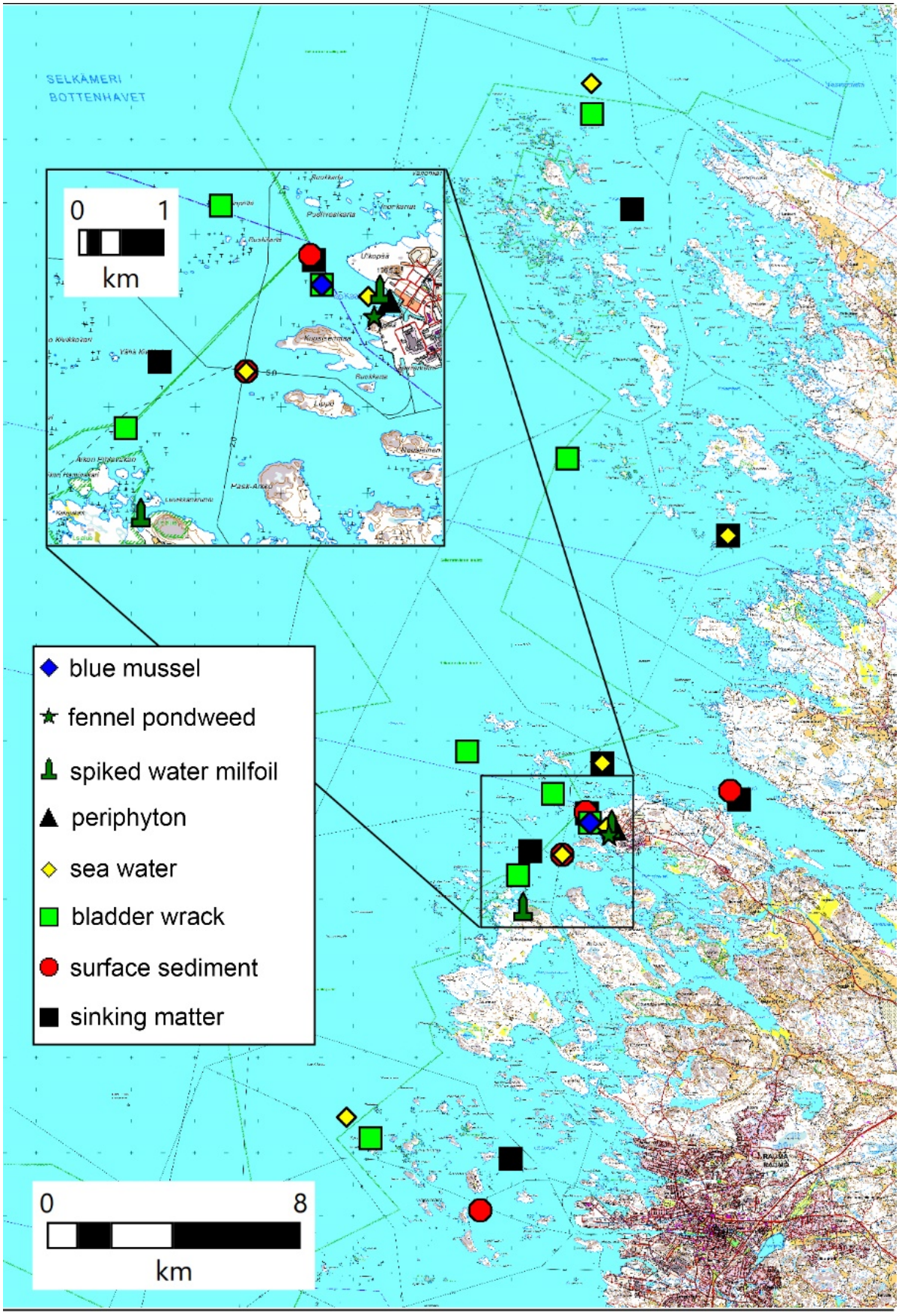


Figure 3. Sampling points in the marine environment of Olkiluoto. The map includes data from the Topographic Database 04/2016 of the National Land Survey of Finland.

Figure 4. A collector of sinking matter (on the left) and a bottom set pot for catching mesidothea entomon (on the right). Photos: STUK.

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, which sinks into the sediment due to its own weight or additional weights and the closure mechanism locks the sediment plug inside the collector.

Periphyton is collected onto a 50 x 50 cm on polycarbonate plate throughout the growing season (May–November). Factors affecting the growth of periphyton include flow rate, light and water quality. The water plants that are collected are bladder wrack, fennel pondweed and spiked water milfoil (Figure 5 and Figure 6). The bottom fauna sample species are blue mussel and mesidothea entomon (Figure 6).

Figure 5. Sampling of bladder wrack by means of scuba diving. In the background, the Olkiluoto power plant. Photo: STUK.

Figure 6. Bladder wrack (on the left) and mesidothea entomon (on the right). Photos: STUK.

5.1.4 Inhabitants of the surroundings

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 Sample processing and analysis

The samples are sent to STUK's laboratory in Helsinki for analysis. In the laboratory, each sample is pre-processed according to STUK's accredited procedure. If necessary, the samples are cleaned to only contain the targeted type. Spoiled and contaminated 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 (cutting, cleaning, filleting, etc.). 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, 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, root vegetables 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. Gamma emitters are determined with gamma-spectrometric measurements in STUK's laboratory in Helsinki. 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. 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 catch determination is done by using an inductively coupled plasma-mass spectrometer (ICP-MS). H-3 can be 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 with wet combustion. Plutonium is separated from the other alpha-active radionuclides by ion exchange, and the measurement sample is prepared by coprecipitation 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 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. In the result tables, the marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration. 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 thus activity concentrations do not accurately reflect the peak 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 analyzed 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					
Milk	x	x				
Grazing grass	x			x		
Crops	x	x	x			
Root vegetable	x					
Domestic 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				
Surface sediment	x	x				x
Sinking matter	x					x
Inhabitants of the surroundings	x					

6 Results of environmental monitoring

A total of 445 samples were collected and analysed in the terrestrial and marine environment of the Olkiluoto power plant during 2019. 147 of the samples were STUK's monitoring samples and the rest were part of the licensee's own monitoring programme. A total of 421 samples of the terrestrial and marine environment of the Loviisa power plant were examined during 2019. Of these, 128 were STUK's regulatory oversight samples. In addition to these, the radioactivity of the inhabitants in the surrounding area of both power plants was measured.

The detailed analysis results of the 2019 samples are given in Tables 2–18 and in Annex 5. 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 at least 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, 2019). 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 (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).

Table 2. An air sample supplementing the licensees' monitoring. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 1.1 µBq/m^3 for Co-60 and 1.3–1.4 µBq/m^3 for I-131.

Collection site	Collection period	Co-60 µBq/m^3	I-131 µBq/m^3	Cs-137 µBq/m^3
Olkiluoto	20–24 May 2019	<MDC	<MDC	2.1 ±30%
Loviisa	16–19 September 2019	<MDC	<MDC	1.8 ±34%

Uncertainty at the accuracy of 2 σ

In the licensee's own air measurements, radionuclides originating from the Loviisa power plant were detected in three air samples (Mn-54 and Co-60) in the second quarter and in one air sample (Co-60) in the third quarter. During the annual outage, a small quantity of I-131 (0.7–1.7 µBq/m^3) was detected in a few air samples at Olkiluoto. In one of the July samples, a small quantity of the Sc-46 artificial radionuclide was also detected, but it is unlikely that it would come from the Olkiluoto power plant. At the same time, the same nuclide was also found in air samples of the national environmental monitoring at the Helsinki and Imatra collection stations. The release source failed to be confirmed.

The collection and monitoring of atmospheric deposition samples belong also to the monitoring programme of the licensees. The licensees determine gamma-active radionuclides from the atmospheric deposition samples and Sr-90 is determined from the annual samples 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 0.9–3.6 Bq/m^2. At Olkiluoto, the corresponding range was 0.7–1.8 Bq/m^2. Other detected nuclides originating from the power plants were Co-60 in Loviisa and Mn-54, Co-58 and Co-60 in Olkiluoto. The Sr-90 results of the composite atmospheric deposition samples for the whole year varied between 0.035–0.071 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, 2019).

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

Collection site	Collection period	Sr-90 Bq/m^2
Loviisa 1	31 Dec 2018–31 Dec 2019*	0.051 ±12%
Loviisa 2	31 Dec 2018–31 Dec 2019*	0.035 ±16%
Olkiluoto	27 Dec 2018–27 Dec 2019*	0.071 ±12%

Uncertainty at the accuracy of 2 σ, *composite annual sample

6.2 Terrestrial environment

No nuclides originating from the power plants were detected in terrestrial environment samples (Table 4). No moss sample was collected at Olkiluoto in 2019 and no ferns sample was collected in Loviisa. The Cs-137 concentrations in the terrestrial environment samples varied between different samples. Cs-137 originating from the Chernobyl disaster can still be observed in the environmental samples. The Cs-137 activity concentrations of mushroom samples (trumpet chanterelle, woolly milk cap, pickle milk cap and rufous milk cap) collected in the vicinity of the Loviisa and Olkiluoto power plants varied between 31–1,200 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).

The licensee collected lichen, moss, pine needle and fern samples from the environment of Olkiluoto. In these samples, only natural nuclides and Cs-137 were detected, the concentration of

which varied between 2.2–130 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. 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.

Table 4. Monitoring measurement results of the lichen, moss, needle and fern samples in 2019.

Lichen		**Be-7**	**Cs-137**	**C-14**
Site	**Collection date**	**Bq/kg**	**Bq/kg**	**Bq/kg**
Loviisa	8 Aug 2019	170 ±10%	220 ±10%	
Olkiluoto	30 Jul 2019	140 ±12%	140 ±11%	
Reference sample (Kouvola)	10 Nov 2019	200 ±8%	110 ±8%	
Moss		**Be-7**	**Cs-137**	
Site	**Collection date**	**Bq/kg**	**Bq/kg**	
Loviisa	17 Sep 2019	430 ±12%	1,900 ±10%	
Reference sample (Heijala)	27 Aug 2018	380 ±10%	180 ±10%	
Spruce needles		**Be-7**	**Cs-137**	
Site	**Collection date**	**Bq/kg**	**Bq/kg**	
Loviisa	29 May 2019	11 ±40%	500 ±24%	124 ±10%
Olkiluoto	5 Jun 2019	14 ±12%	130 ±10%	127 ±10%
Reference sample (Lahti)	12 Jun 2019	23 ±14%	6 ±16%	122 ±10%
Ferns		**Be-7**	**Cs-137**	
Site	**Collection date**	**Bq/kg**	**Bq/kg**	
Olkiluoto	31 Jul 2019	66 ±12%	210 ±10%	
Reference sample (Lahti)	26 Jun 2019	57 ±13%	50 ±11%	

Uncertainty at the accuracy of 2 σ

Table 5. Monitoring measurement results of the mushroom samples in 2019.

Mushrooms Site	Collection date	Species	Cs-137 Bq/kg FW
Loviisa	1 Oct 2019	Trumpet chanterelle	210 ±10%
		Woolly milk cap	31 ±10%
		Rufous milk cap	1,200 ±8%
		Rufous milk cap	620 ±11%
Olkiluoto	24 Sep 2019	Pickle milk cap	200 ±11%
		Rufous milk cap	170 ±11%
	25 Sep 2019	Rufous milk cap	93 ±11%
		Rufous milk cap	390 ±11%

Uncertainty at the accuracy of 2 σ

The activity concentrations of Cs-13 in milk samples varied between 0.1–0.7 Bq/l (Table 6) in the environmental radiation monitoring programmes of the nuclear power plants. In the combined yearly samples (samples from 20 - 40 km distance from the power plants) the S-90 concentration was 0,02 Bq/l in Loviisa and 0,03 Bq/l in Olkiluoto. The activity concentrations are well in line with the activity concentrations of the national environmental monitoring of milk samples, which were between 0.13–1.2 Bq/l for Cs-137 and between 0.02–0.03 Bq/l for Sr-90 in 2018 (Mattila and Inkinen, 2019). Figures 7 and 8 show the activity concentration of Cs-137 in milk samples of the environmental monitoring programmes of the nuclear power plants in 2010–2019. 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 0.008–0.03 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. Crops showed no Sr-89 and their Sr-90 activity concentration was between 0.07–0.4 Bq/kg. 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.

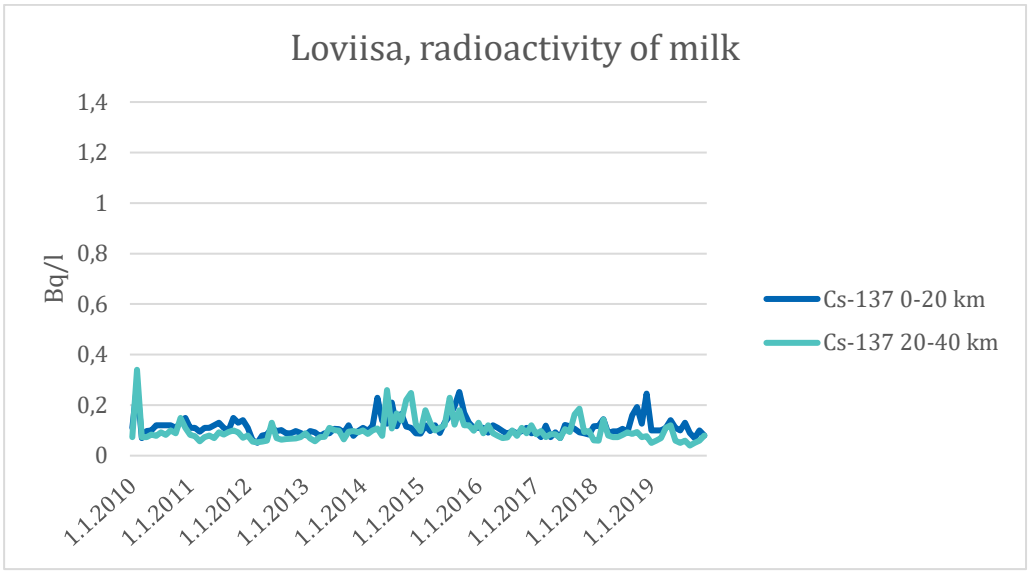


Figure 7. The Cs-137 concentration (Bq/l) of the milk samples supplied by dairies in the surroundings of the Loviisa power plant (distance of the dairies from the plant 0–20 km or 20–40 km) in 2010–2019.

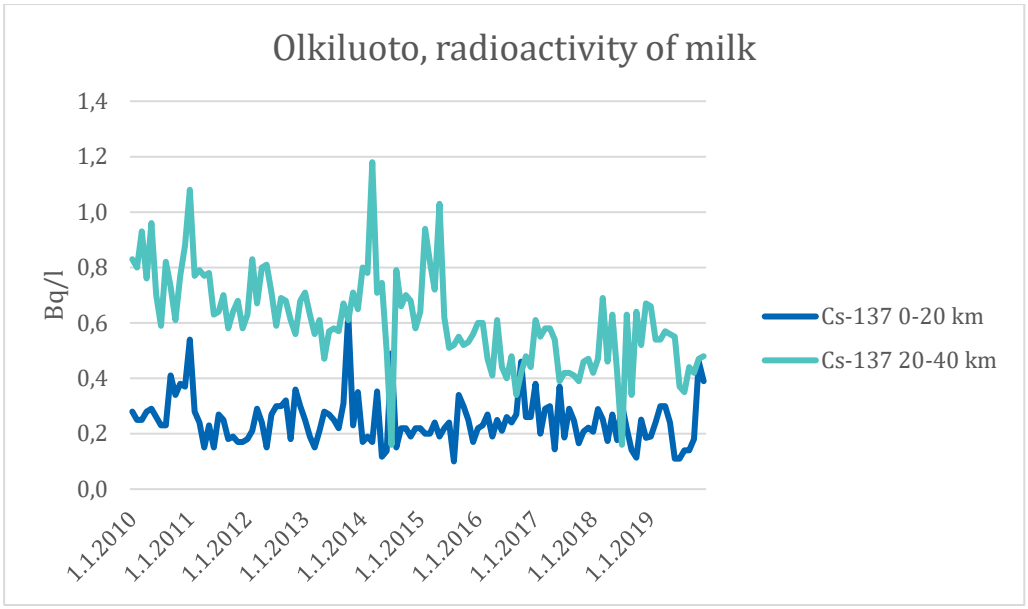


Figure 8. The Cs-137 concentration (Bq/l) of the milk samples supplied by dairies in the surroundings of the Olkiluoto power plant (distance of the dairies from the plant 0–20 km or 20–40 km) in 2010–2019.

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 2019.

		0–20 km		20–40 km	
		K-40	Cs-137	K-40	Cs-137
Collection site	Collection period	Bq/l	Bq/l	Bq/l	Bq/l
Olkiluoto	6–27 Jan 2019	48 ±15%	0.19 ±12%	49 ±15%	0.66 ±11%
	3–24 Feb 2019	49 ±16%	0.24 ±15%	53 ±15%	0.54 ±15%
	3–31 Mar 2019	52 ±16%	0.30 ±15%	51 ±12%	0.54 ±14%
	7–28 Apr 2019	50 ±15%	0.30 ±11%	51 ±12%	0.57 ±14%
	5–26 May 2019	49 ±15%	0.24 ±10%	52 ±16%	0.56 ±15%
	2–30 Jun 2019	49 ±16%	0.11 ±17%	47 ±15%	0.55 ±11%
	7–28 Jul 2019	51 ±16%	0.11 ±17%	51 ±16%	0.37 ±15%
	4–25 Aug 2019	54 ±19%	0.14 ±13%	52 ±19%	0.35 ±11%
	1–29 Sep 2019	55 ±19%	0.14 ±12%	54 ±15%	0.44 ±15%
	6–27 Oct 2019	51 ±16%	0.18 ±16%	48 ±14%	0.42 ±16%
	3–24 Nov 2019	49 ±16%	0.46 ±12%	49 ±12%	0.47 ±12%
	1–29 Dec 2019	52 ±12%	0.39 ±14%	4.8 ±16%	0.48 ±12%
Loviisa	6–27 Jan 2019	46 ±15%	0.10 ±17%	50 ±15%	0.05 ±19%
	3–24 Feb 2019	48 ±16%	0.10 ±16%	53 ±16%	0.06 ±19%
	3–31 Mar 2019	49 ±17%	0.10 ±14%	50 ±15%	0.07 ±16%
	7–28 Apr 2019	51 ±16%	0.11 ±17%	50 ±17%	0.11 ±14%
	5–26 May 2019	50 ±16%	0.14 ±15%	52 ±15%	0.12 ±13%
	2–30 Jun 2019	49 ±16%	0.11 ±17%	48 ±15%	0.06 ±22%
	7–28 Jul 2019	52 ±19%	0.10 ±11%	52 ±15%	0.05 ±22%
	4–25 Aug 2019	52 ±19%	0.13 ±13%	49 ±16%	0.06 ±20%
	1–29 Sep 2019	45 ±26%	0.09 ±15%	51 ±16%	0.04 ±22%
	6–27 Oct 2019	46 ±16%	0.07 ±18%	47 ±14%	0.05 ±20%
	3–24 Nov 2019	47 ±14%	0.10 ±16%	50 ±16%	0.06 ±20%
	1–29 Dec 2019	46 ±14%	0.08 ±16%	54 ±16%	0.08 ±20%
				20–40 km	
				Sr-90	
				Bq/l	
Loviisa	6 Jan–29 Dec 2019*			0.02 ±14%	
Olkiluoto	6 Jan–29 Dec 2019*			0.03 ±12%	

Uncertainty at the accuracy of 2 σ, *composite annual sample

Table 7. Monitoring measurement results of the grazing grass, crops, meat and root vegetable samples in 2019.

Grazing grass			**C-14**	**K-40**	**Sr-90**	**Cs-137**
Site	**Collection date**	**Species**	**Bq/kg DW**	**Bq/kg DW**		**Bq/kg DW**
Loviisa	19 Sep 2019	Grazing grass	114 ±10%	850 ±15%		0.38 ±42%
Olkiluoto	4 Jun 2019	Grazing grass	114 ±10%	770 ±15%		1.1 ±19%
Reference (Kouvola)	15 Sep 2019	Grazing grass	112 ±10%	660 ±17%		16 ±11%
Crops				**K-40**	**Sr-90**	**Cs-137**
Site	**Collection date**			**Bq/kg DW**	**Bq/kg DW**	**Bq/kg DW**
Loviisa	15 Nov 2019	Wheat		130 ±15%	0.4 ±10%	0.13 ±54%
		Barley		180 ±17%		0.30 ±28%
Olkiluoto	28 Oct 2019	Wheat		120 ±15%	0.07 ±12%	0.4 ±20%
	28 Oct 2019	Oat		120 ±15%		0.9 ±19%
Reference (Kouvola)	29 Sep 2019	Wheat		110 ±15%		0.7 ±15%
Reference (Kouvola)	29 Sep 2019	Barley		110 ±17%		0.3 ±16%
Root vegetable				**K-40**		**Cs-137**
Site	**Collection date**			Bq/kg FW		Bq/kg FW
Loviisa	22 Nov 2019	Potato		150 ±15%		0.15 ±28%
Olkiluoto	11 Sep 2019	Potato		110 ±12%		0.08 ±44%

Uncertainty at the accuracy of 2 σ

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 2019. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.95 Bq/l for H-3 and 0.37–0.42 Bq/m^3 for Cs-137.

Site	Collection date	H-3 Bq/l	Sr-90 Bq/m^3	Cs-137 Bq/m^3
Rauma	22 Jan 2019	1.1 ±54%		3.0 ±12%
Rauma	29 Oct 2019	1.0 ±60%		1.6 ±19%
Rauma	22 Jan–29 Oct 2019*		5.5 ±9%	
Olkiluoto power plant	22 Jan–25 Sep 2019*		4.2 ±9%	
Loviisa	13 Mar 2019			<MDC
Loviisa	15 Nov 2019	<MDC		<MDC
Loviisa	13 Mar–15 Nov 2019*		0.09 ±50%	
Loviisa power plant	28 Feb–29 Nov 2019*		3.4 ±9%	

Uncertainty at the accuracy of 2 σ, *composite annual sample

No artificial radionuclides were found in either of the groundwater samples taken in the surroundings of Loviisa and Olkiluoto. Same radionuclides were found in a sludge sample taken at the Vårdö wastewater treatment plant near Loviisa as in the sludge samples of the Viikinmäki wastewater treatment plant examined in the national environmental radiation monitoring programme (Mattila and Inkinen, 2019). The I-131 concentration of the Vårdö sludge sample was 4,600 Bq/kg per dry weight of the sample at the time of sampling. I-131 is a radionuclide commonly used at hospitals in isotope treatments and, therefore, it probably originates from a source other than the power plant.

6.3 Marine environment

Small quantities of 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. In September and October, unusual but small concentrations of radionuclides originating from the power plant were detected in some of the samples of the Olkiluoto marine environment. The elevated radionuclide concentrations were related to a failure of the liquid waste processing system at unit 1 of the Olkiluoto power plant, which temporarily reduced the system's ability to remove radioactive substances from the discharged water. STUK published an announcement on the incident on 29 November 2019. However, the releases from Olkiluoto fall clearly below the radioactivity limits set for the water discharges from the nuclear power plant.

Tables 9 and 10 show the monitoring measurement results of the seawater samples in 2019. The result tables indicate the location name of the sampling point. 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, however, 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 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.

In September, small quantities of Co-60 and the short-lived isotope Cs-134 of caesium and an elevated concentration of H-3 were detected in a seawater sample collected at Olkiluoto. These observations are linked to the failure of the plant's wastewater processing system. In the longer time series (Figures 9 and 10), 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 majority of the samples less than 2 Bq/l. Only two seawater samples showed a slightly elevated activity concentration of H-3: in Loviisa in the second quarter (2.3 Bq/l) and at Olkiluoto in June (6.2 Bq/l). 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 2019. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.94 Bq/l for H-3, 0.59–0.88 Bq/m^3 for Co-60 and 0.7–1.3 Bq/m^3 for Cs-134.

		H-3	Co-60	Sr-90	Cs-137
Site	Date	Bq/l	Bq/m^3	Bq/m^3	Bq/m^3
Halkokari A	4 Apr 2019	9.5 ±13%	<MDC	5.7 ±9%	13 ±12%
	9 Oct 2019	1.6 ±42%	<MDC	6.0 ±10%	13 ±12%
	14 Nov 2019	1.9 ±34%	<MDC	6.1 ±10%	14 ±15%
Klobbfjärden 1	4 Apr 2019	7.2 ±15%	<MDC		12 ±12%
	12 Nov 2019	3.6 ±22%	<MDC		13 ±14%
Vådholmsfjärden 4	3 Apr 2019	3.0 ±26%	<MDC		14 ±11%
	12 Nov 2019	2.1 ±32%	<MDC		15 ±15%
Hudöfjärden 8	4 Apr 2019	2.4 ±30%	<MDC		14 ±15%
	14 Nov 2019	1.2 ±50%	<MDC		14 ±17%
Påsalöfjärden R1	2 May 2019	2.0 ±34%	<MDC	5.8 ±10%	9.9 ±13%
	12 Nov 2019	<MDC	<MDC	6.0 ±10%	10 ±15%

Uncertainty at the accuracy of 2 σ

Table 10. Monitoring measurement results of the Olkiluoto seawater samples in 2019. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.94–0.99 Bq/l for H-3, 0.93–1.8 Bq/m^3 for Co-60 and 0.7–1.3 Bq/m^3 for Cs-134.

Site	Date	H-3 Bq/l	Co-60 Bq/m^3	Sr-90 Bq/m^3	Cs-137 Bq/m^3	Cs-134 Bq/m^3
Iso Kaalonperä 13	10 Apr 2019	<MDC	<MDC	5.8 ±9%	21 ±11%	<MDC
	26 Sep 2019	21 ±11%	1.2 ±34%	6.4 ±10%	26 ±12%	0.9 ±42%
	22 Nov 2019	<MDC	<MDC	6.1 ±10%	20 ±13%	<MDC
Liponluoto 2	10 Apr 2019	<MDC	<MDC		22 ±11%	<MDC
	22 Nov 2019	<MDC	<MDC		19 ±13%	<MDC
Rääpinkivet 3	10 Apr 2019	<MDC	<MDC		20 ±13%	<MDC
	20 Nov 2019	<MDC	<MDC		21 ±14%	<MDC
Santakari 15	11 Apr 2019	1.4 ±48%	<MDC		17 ±14%	<MDC
	19 Nov 2019	<MDC	<MDC		20 ±13%	<MDC
Kylmäpihlaja 17	11 Apr 2019	<MDC	<MDC		22 ±12%	<MDC
	21 Nov 2019	<MDC	<MDC		20 ±14%	<MDC
Viikari 16	11 Apr 2019	1.2 ±54%	<MDC	6.3 ±10%	21 ±13%	<MDC
	19 Nov 2019	<MDC	<MDC	6.6 ±10%	19 ±11%	<MDC

Uncertainty at the accuracy of 2 σ

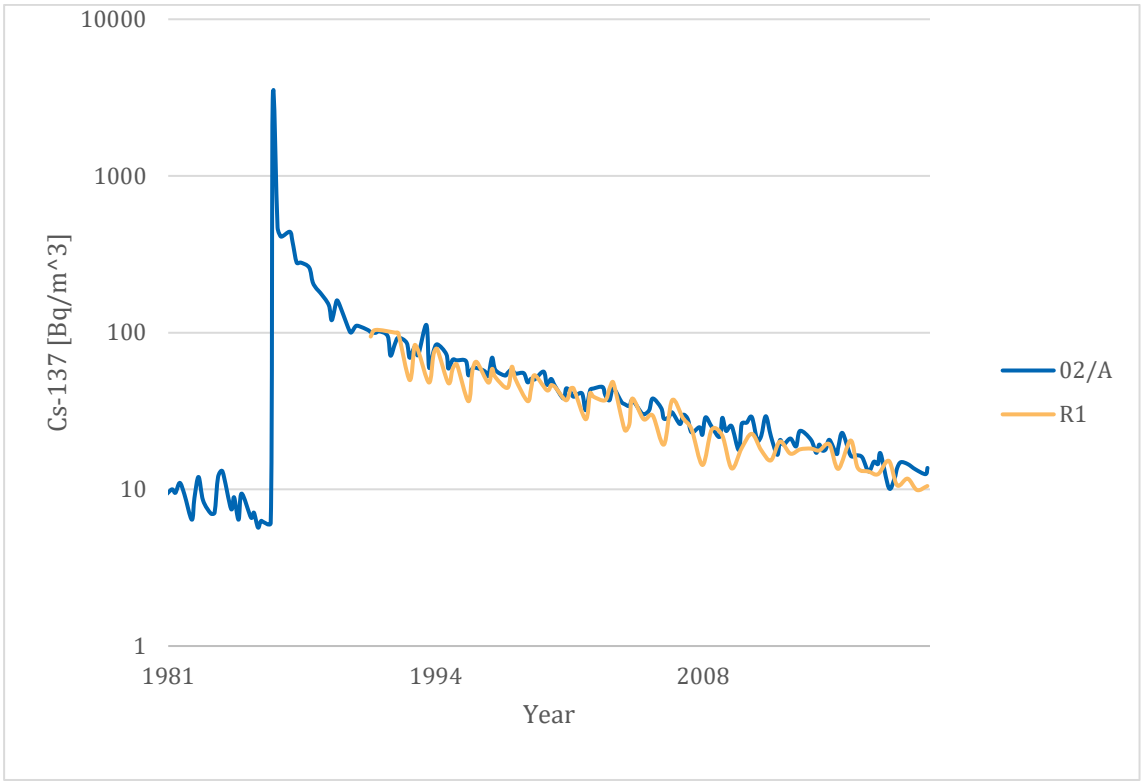


Figure 9. The Cs-137 activity concentration in seawater at the nearest (02/A, blue) and furthest (R1, yellow) sampling point of the Loviisa power plant in 1980–2019 presented on a logarithmic scale.

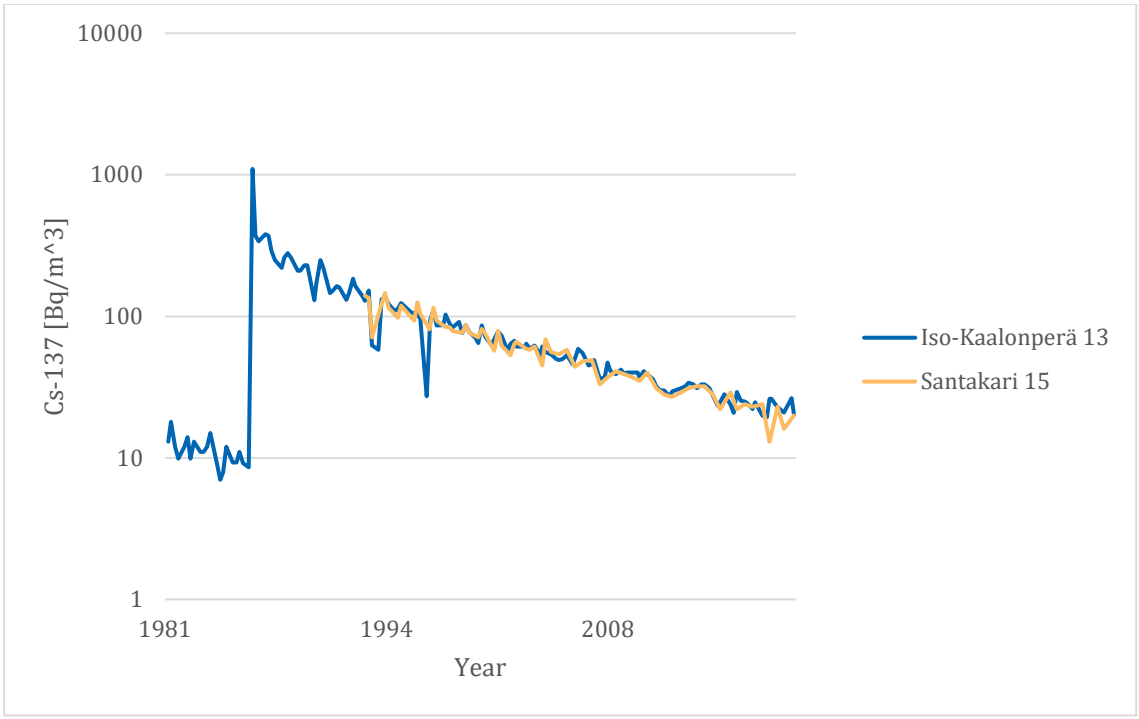


Figure 10. The Cs-137 activity concentration in seawater at the nearest (Iso-Kaalonperä 13, blue) and furthest (Santakari 15, yellow) sampling point of the Olkiluoto power plant in 1981–2019 presented on a logarithmic scale.

The Cs-137 concentrations of fish samples (Baltic herring, perch, pike, bream and roach) caught in the vicinity of the power plants varied between 2.0–13 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, 2019). The concentrations of Sr-90 in the fish samples were also low. The Cs-137 activity concentrations in the fry samples received from the Smoltti fish farm in Loviisa were 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 2019. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.09 Bq/kg for Cs-137.

Sample species	Site	Period	Cs-137 Bq/kg (FW)	Sr-90 Bq/kg (FW)
Baltic herring	Loviisa 0–10 km	3 Oct 2019	2.4 ±17%	0.021 ±26%
Baltic herring	Olkiluoto 0–10 km	20 May 2019	2.3 ±15%	0.028 ±18%
Baltic herring	Reference	3 Oct 2019	1.8 ±15%	
Perch	Loviisa 0–2 km	13–14 May 2019	8.1 ±22%	0.013 ±30%
	Loviisa 2–10 km	28 May–10 Oct 2019	6.8 ±12%	
	Olkiluoto 0–3 km	20 May–7 Jun 2019	11 ±17%	0.012 ±36%
	Olkiluoto 3–10 km	20 May–7 Jun 2019	13 ±13%	
Pike	Loviisa 0–2 km	12 Jun–2 Oct 2019	5.8 ±17%	
	Loviisa 2–10 km	16 May–7 Aug 2019	6.2 ±13%	
	Olkiluoto 0–3 km	20 May 2019	8.2 ±17%	
	Olkiluoto 3–10 km	5 Jun–3 Sep 2019	9.5 ±17%	
Pike	Reference (Pellinki)	11 Sep 2019	5.2 ±11%	
Bream	Loviisa 0–2 km	15 May 2019	2.0 ± 3%	
	Loviisa 2–10 km	29 May 2019	2.2 ±17%	
	Olkiluoto 3–10 km	23 May 2019	2.8 ±10%	
Roach*	Olkiluoto 0–3 km	17 Oct 2019	3.0 ±11%	
Fry	Loviisa Smoltti	24 Jun 2019	<MDC	
		26 Nov 2019	0.64 ±20%	

Uncertainty at the accuracy of 2 σ. * At Olkiluoto, the roach substitutes the bream

Table 12. Monitoring measurement results of the bottom fauna collected from the marine environment of Loviisa and Olkiluoto in 2019. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.2–0.4 Bq/kg for Ag-110m.

Sample species	Site	Collection period	Cs-137 Bq/kg	Ag-110m Bq/kg	Sr-90 Bq/kg
Mesidothea entomon	Loviisa	14 May–8 Aug 2019	5.5 ±24%	1.4 ±26%	7.3 ±10%
Blue mussel	Olkiluoto	22 Aug 2019	0.63 ±20%	<MDC	6.9 ±13%
Blue mussel	Olkiluoto	4–26 Sep 2019	1.8 ±24%	<MDC	6.4 ±13%

Uncertainty at the accuracy of 2 σ

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 11 and 12 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 13 and 14 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. Loviisa power plant performs every fourth year a release of evaporation concentrate tank's surface water causing an increase e.g. in the amount of released Co-60. These releases are performed at the end of the year to minimize the effects of nutrients in the release. For this reason the effects of these releases are observable only in the samples of the following growth season.

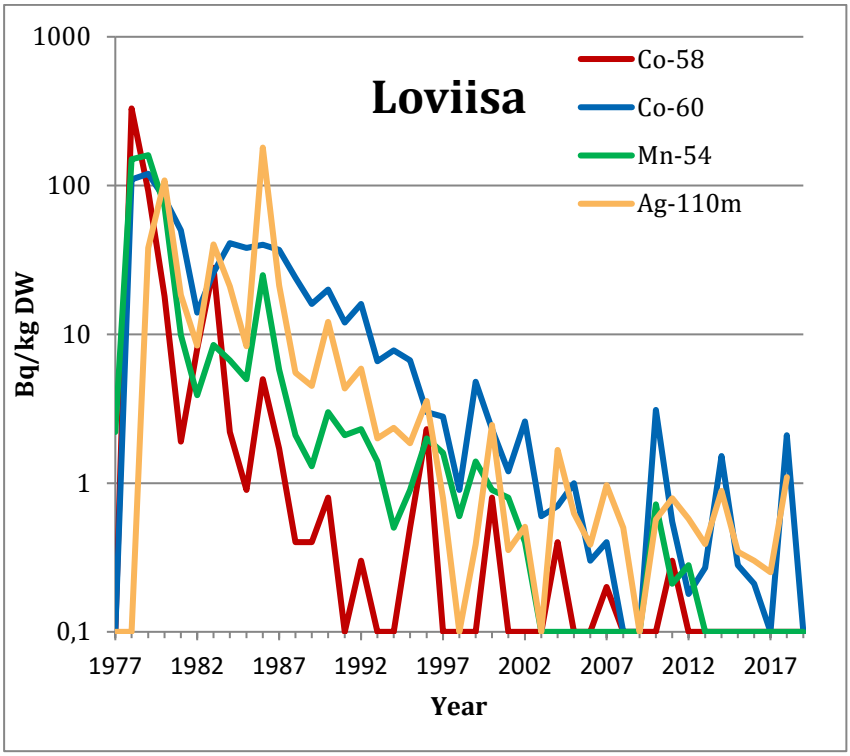


Figure 11. Averages of the activity concentrations of the most significant radionuclides originating from the power plant in bladder wrack (Bq/kg per dry weight) at the nearest sampling point of the Loviisa power plant in 1977–2019 on a logarithmic scale.

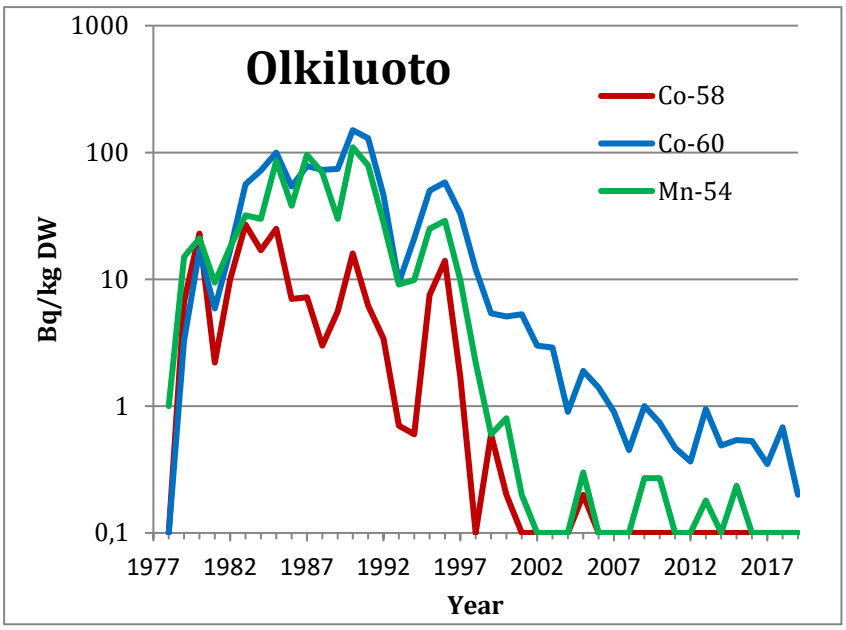


Figure 12. Averages of the activity concentrations of the most significant radionuclides originating from the power plant in bladder wrack (Bq/kg per dry weight) at the nearest sampling point of the Olkiluoto power plant in 1977–2019 on a logarithmic scale.

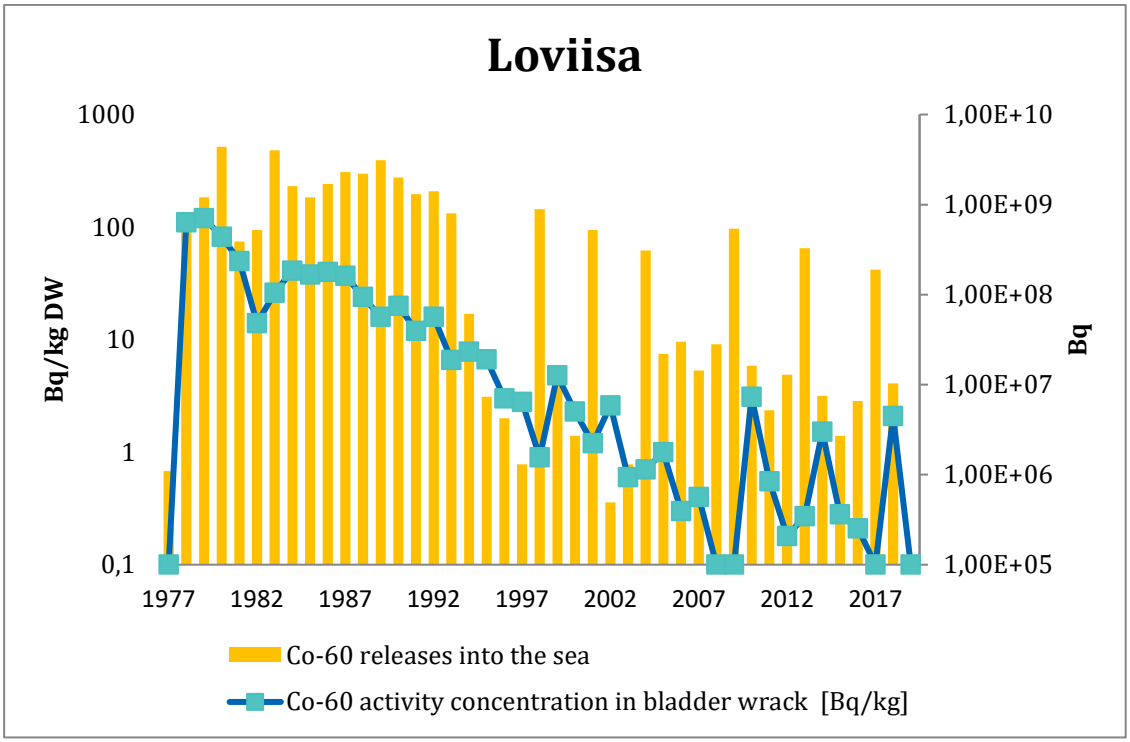


Figure 13. The Co-60 releases into the sea and the average of the Co-60 activity concentration in the bladder wrack samples of the nearest sampling point of the Loviisa power plant in 1977–2019.

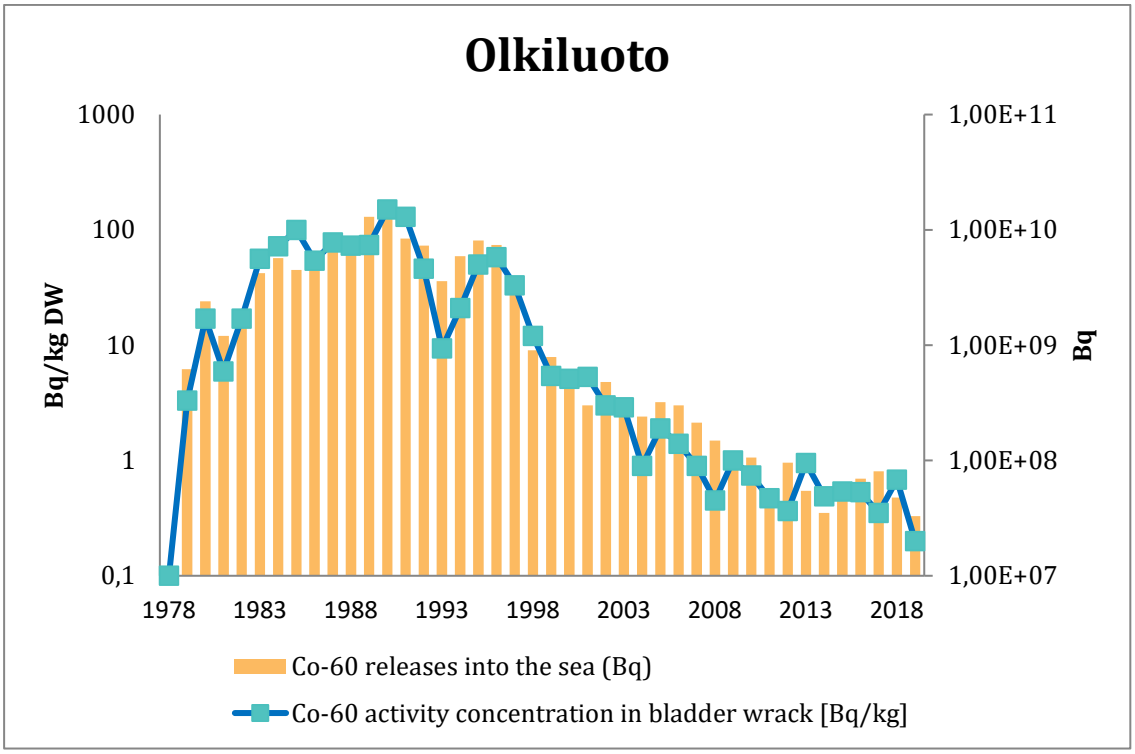


Figure 14. The Co-60 releases into the sea and the average of the Co-60 activity concentration in the bladder wrack samples of the nearest sampling point of the Olkiluoto power plant in 1977–2019.

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-58, Co-60 and Sb-124 and those of Olkiluoto were Cr-51, Mn-54, Co-60, I-131, Cs-134 and Ce-141. In addition to the periphyton samples, some observations of radionuclides originating from the power plants were also made in the bladder wrack samples (Table 13 and 14). Co-60, Ag-110m and I-131 were found in Loviisa. The Cs-137 activity concentrations of bladder wrack varied between 9.7–16 Bq/kg. In Olkiluoto, Co-60 was observed in bladder wrack, and the Cs-137 activity concentrations were between 6.1–17 Bq/kg. 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 (Table 15). Mn-54, Co-58 and Co-60 were found in the aquatic plants with submerged leaves collected from the discharge areas of both power plants; in addition, I-131 was found in the spiked water milfoil samples of the Olkiluoto discharge area. 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, 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. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.11–0.55 Bq/kg for Co-60, 0.15–0.44 Bq/kg for Ag-110m, 0.33–0.54 Bq/kg for I-131 and 0.021–0.014 Bq/kg for Pu-238.

Sampling point	Collection date	Co-60 Bq/kg	Ag-110m Bq/kg	I-131 Bq/kg	Cs-137 Bq/kg	Sr-90 Bq/kg	Pu-238 Bq/kg	Pu-239, Pu-240 Bq/kg
Stenörarna	18 Sep 2019	<MDC	<MDC	0.39 ±42%	14 ±11%			
Björkholmen B1	14 May 2019	0.42 ±24%	0.27 ±22%	<MDC	12 ±17%			
	18 Sep 2019	<MDC	0.76 ±38%	<MDC	16 ±19%	5.5 ±11%	< 0.021	0.12 ±18%
Lilla Djupberget C	14 May 2019	<MDC	<MDC	<MDC	12 ±18%			
	17 Sep 2019	<MDC	<MDC	<MDC	12 ±19%			
Boisto D	14 May 2019	<MDC	<MDC	<MDC	12 ±11%			
	17 Sep 2019	<MDC	<MDC	<MDC	14 ±17%			
Storskarven E	14 May 2019	<MDC	<MDC	<MDC	11 ±17%	5.7 ±10%		
	17 Sep 2019	<MDC	<MDC	<MDC	9.7 ±11%		<MDC	0.05 ±23%

Uncertainty at the accuracy of 2 σ

Table 14. Radionuclides found in the bladder wrack samples collected in the marine environment of Olkiluoto. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.09–0.44 Bq/kg for Co-60 and 0.01 Bq/kg for Pu-238.

Sampling point	Collection date	Co-60 Bq/kg	Cs-137 Bq/kg	Sr-90 Bq/kg	Pu-238 Bq/kg	Pu-239, Pu-240 Bq/kg
Iso Kaalonperä	9 May 2019	0.22 ±20%	17 ±11%			
	20 Aug 2019	0.18 ±24%	12 ±11%	6.1 ±11%	< 0.01	0.07 ±20%
Kalliopöllä	9 May 2019	0.12 ±56%	15 ±11%			
	20 Aug 2019	<MDC	10 ±11%			
Reimarkrunni	9 May 2019	<MDC	13 ±12%			
	20 Aug 2019	<MDC	9.5 ±11%			
Iso-Siiliö	9 May 2019	<MDC	10 ±11%			
	22 Aug 2019	<MDC	7.3 ±11%			
Iso-Pietari	8 May 2019	<MDC	13 ±19%			
	21 Aug 2019	<MDC	9.9 ±11%			
Kylmäpihlaja	9 May 2019	<MDC	10 ±11%			
	22 Aug 2019	<MDC	6.1 ±15%			
Viikari	8 May 2019	<MDC	11 ±11%			
	21 Aug 2019	<MDC	7.6 ±11%	5.4 ±10%	< 0.01	0.02 ±27%

Uncertainty at the accuracy of 2 σ

Table 15. Radionuclides found in the aquatic plants with submerged leaves collected from the marine environment of Loviisa and Olkiluoto. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.10–0.75 Bq/kg for Mn-54, 0.14–0.74 Bq/kg for Co-58, 0.31–0.82 Bq/kg for Co-60 and 0.52 Bq/kg for I-131.

Sampling point	Species	Collection date	Mn-54 Bq/kg	Co-58 Bq/kg	Co-60 Bq/kg	I-131 Bq/kg	Cs-137 Bq/kg
Loviisa discharge area	spiked water milfoil	12 Sep 2019	2.6	1.5 ±14%	0.77 ±19%	<MDC	5.6 ±19%
	fennel pondweed	12 Sep 2019	<MDC	<MDC	<MDC	<MDC	2.9 ±20%
Loviisa reference	spiked water milfoil	11 Sep 2019	<MDC	<MDC	<MDC	<MDC	16 ±12%
Olkiluoto discharge area	spiked water milfoil	23 Aug 2019	<MDC	<MDC	0.47 ±42%	<MDC	7.8 ±11%

		29 Oct 2019	0.97 ±11%	0.08 ±20%	4.0 ±9%	1.4 ±10%	27 ±8%
		22 Nov 2019	0.46 ±22%	<MDC	3.3 ±9%	0.27 ±42%	17 ±11%
	fennel pondweed	3 Sep 2019	<MDC	<MDC	0.17 ±28%	<MDC	4.0 ±11%
Olkiluoto reference	spiked water milfoil	3 Sep 2019	<MDC	<MDC	< 0.31	<MDC	15 ±17%

Uncertainty at the accuracy of 2 σ

Small concentrations of radionuclides originating from the power plants were found in the sinking matter samples collected from the environment of the power plants (Table 16 and 17). Co-60 (0.68–60 Bq/kg), Ag-110m (1.5–9.4 Bq/kg) and Cs-137 (180–350 Bq/kg) were found in Loviisa and Co-60 (0.41–2.6 Bq/kg) and Cs-137 (99–210 Bq/kg) at Olkiluoto. Cs-137 found in the sinking matter originates largely from the Chernobyl disaster.

Table 16. Radionuclides observed in the sinking matter samples collected from the marine environment of Loviisa. The marking <MDC means that the activity concentration of the radionuclide is below the detectable concentration, which was 0.44–2.6 Bq/kg for Co-60, 0.78–2.9 Bq/kg for Ag-110m and 0.011–0.067 Bq/kg for Pu-228.

Sampling point	Collection period	Co-60 Bq/kg	Ag-110m Bq/kg	Cs-137 Bq/kg	Pu-238 Bq/kg	Pu-239, Pu-240 Bq/kg
Hästholmsfjärden 5S	4 Dec 2018–4 Apr 2019	60 ±13%	2.9 ±24%	280 ±11%		
	4 Apr–11 Jun 2019	0.68 ±22%	2.7 ±11%	190 ±11%		
	11 Jun–6 Aug 2019	<MDC	4.3 ±22%	180 ±11%		
	6 Aug–13 Nov 2019	1.0 ±44%	2.9 ±28%	260 ±17%		
	4 Dec 2018–13 Nov 2019				<MDC	0.85 ±13%
Hästholmsfjärden 3	8 Nov 2018–11 Jun 2019	0.77 ±30%	2.7 ±24%	220 ±11%		
	11 Jun–6 Aug 2019	<MDC	<MDC	200 ±11%		
	6 Aug–13 Nov 2019	1.5 ±15%	9.4 ±17%	270 ±13%		
Klobbfjärden 1	8 Nov 2018–11 Jun 2019	<MDC	1.5 ±20%	300 ±13%		
	11 Jun–6 Aug 2019	<MDC	<MDC	260 ±16%		
	6 Aug–13 Nov 2019	<MDC	<MDC	350 ±12%		
Vådholmsfjärden 4	8 Nov 2018–11 Jun 2019	<MDC	<MDC	250 ±13%		
	11 Jun–6 Aug 2019	<MDC	<MDC	260 ±16%		
	6 Aug–12 Nov 2019	<MDC	<MDC	310 ±9%		
Påsalöfjärden R1	7 Nov 2018–2 May 2019	<MDC	<MDC	220 ±11%		
	2 May–12 Jun 2019	<MDC	<MDC	210 ±17%		
	12 Jun–7 Aug 2019	<MDC	<MDC	230 ±11%		
	7 Nov 2018–12 Nov 2019				<MDC	0.36 ±14%

Uncertainty at the accuracy of 2 σ

Table 17. Radionuclides observed in the sinking matter samples collected from the marine environment of Olkiluoto. The marking <MDC means that the activity concentration is below the detectable concentration, which was 0.36–2.1 Bq/kg for Co-60 and 0.008 Bq/kg for Pu-228.

Sampling point	Collection period	Co-60 Bq/kg	Cs-137 Bq/kg	Pu-238 Bq/kg	Pu-239, Pu-240 Bq/kg
Rääpinkivet 3	31 Oct 2018–10 Apr 2019	0.41 ±44%	160 ±10%		
Rääpinkivet 3	10 Apr–19 Jun 2019	<MDC	99 ±17%		
Rääpinkivet 3	19 Jun–14 Aug 2019	<MDC	110 ±17%		
Rääpinkivet 3	31 Oct 2018–20 Nov 2019			<MDC	0.68 ±13%
Vähä Kivikkokari 12	1 Nov 2018–10 Apr 2019	0.59 ±40%	190 ±16%		
Vähä Kivikkokari 12	10 Apr–18 Jun 2019	<MDC	130 ±18%		
Vähä Kivikkokari 12	18 Jun–13 Aug 2019	<MDC	160 ±9%		
Vähä Kivikkokari 12	13 Aug–21 Nov 2019	<MDC	160 ±13%		
Kaalonperä 9	31 Oct 2018–10 Apr 2019	0.97 ±26%	170 ±13%		
Kaalonperä 9	10 Apr–18 Jun 2019	2.6 ±18%	150 ±13%		
Kaalonperä 9	18 Jun–14 Aug 2019	<MDC	170 ±12%		
Kaalonperä 9	14 Aug–29 Oct 2019	0.88 ±20%	160 ±10%		
Santakari 15	13 Nov 2018–11 Apr 2019	<MDC	200 ±8%		
Santakari 15	11 Apr–19 Jun 2019	<MDC	100 ±11%		
Santakari 15	19 Jun–14 Aug 2019	<MDC	210 ±11%		
Kuuskajaskari 20	1 Nov 2018–11 Apr 2019	<MDC	160 ±17%		
Kuuskajaskari 20	11 Apr–18 Jun 2019	<MDC	140 ±22%		
Kuuskajaskari 20	18 Jun–13 Aug 2019	<MDC	150 ±14%		
Kuuskajaskari 20	13 Aug–21 Nov 2019	<MDC	160 ±13%		
Keskivedenkari 18	13 Nov 2018–11 Apr 2019	<MDC	160 ±12%		
Keskivedenkari 18	11 Apr–19 Jun 2019	<MDC	130 ±17%		
Keskivedenkari 18	19 Jun–14 Aug 2019	<MDC	130 ±16%		
Keskivedenkari 18	13 Nov 2018–19 Nov 2019			0.024 ±16%	0.057 ±13%

Uncertainty at the accuracy of 2 σ

Radionuclides originating from the power plants were found in surface sediment in the marine environment of the power plants (Table 18). Co-60 (0.69–1.3 Bq/kg) and Ag-110m (0.96–2.2 Bq/kg) were found in Loviisa, and the Cs-137 concentration of sediment in the vicinity was between 290–400 Bq/kg. Co-60 (0.79–0.91 Bq/kg) was found at Olkiluoto, and the Cs-137 concentration of sediment in the vicinity was between 200–220 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 220–250 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 18. Radioactive substances found in the marine environment sediment samples. The marking <MDC means that the activity concentration is below the detectable concentration, which was 0.35–0.77 Bq/kg for Co-60, 0.66–0.96 Bq/kg for Ag-110m and 0.011–0.015 Bq/kg for Pu-238.

	Collection date	Co-60 Bq/kg	Ag-110m Bq/kg	Cs-137 Bq/kg	Sr-90 Bq/kg	Pu-238 Bq/kg	Pu-239, Pu-240 Bq/kg
Loviisa							
Hästholmsfjärden 5	11 Oct 2019	1.3 ±34%	1.8 ±15%	330 ±13%	0.8 ±14%	0.01 ±20%	1.0 ±12%
Hästholmsfjärden 3	10 Oct 2019	0.90 ±28%	2.2 ±16%	290 ±13%	0.8 ±15%	<MDC	1.0 ±13%
Klobbfjärden 1	10 Oct 2019	0.69 ±32%	0.96 ±22	400 ±17%	0.4 ±20%	<MDC	1.5 ±13%
Vådholmsfjärden 4	10 Oct 2019	<MDC	<MDC	340 ±12%	2.0 ±12%	0.009	1.3 ±12
Påsalofjärden R1 (reference sample)	9 Oct 2019	<MDC	<MDC	250 ±11%	2.1 ±11%	<MDC	0.4 ±14%
Olkiluoto							
Kaalonperä 9	6 Jun 2019	0.79 ±34%	<MDC	200 ±11%	0.3 ±22%	0.017 ±20%	0.9 ±13%
Liponluoto 2	6 Jun 2019	0.91 ±22%	<MDC	210 ±9%	0.6 ±15%	<MDC	0.9 ±13%
Tankarit 4	6 Jun 2019	0.80 ±17%	<MDC	220 ±13%	0.7 ±15%	<MDC	0.8 ±16%
Olkiluoto S8 (reference sample)	6 Jun 2019	<MDC	<MDC	220 ±17%	0.7 ±14%	<MDC	1.1 ±13%

Uncertainty at the accuracy of 2 σ

6.4 Inhabitants of the surroundings

No radioactive substances originating from the power plants were observed in the bodies of people living close to the nuclear power plants.

7 Summary and conclusions

In 2019, 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 licensee from external air and in samples collected from the marine environment. The terrestrial environment samples showed mainly only 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 power plant technology. The quantities of radioactive substances 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 2019 less than 1% of the limit of 0.1 millisieverts set in the Nuclear Energy Decree (161/1988) (Kainulainen, 2019).

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 2019.

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 that have been observed in the marine environment in the previous years. The samples collected from the marine environment of the Olkiluoto nuclear facility in the autumn showed small quantities of radioactive substances, which are rarely detected in the marine environment near the power plants. The reason for this was a malfunction in the wastewater processing system of the plant. The event did not have an effect on the radiation exposure of the environment or people.

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

Fortum Power and Heat Oy (2020), Ympäristön säteilyturvallisuuden vuosiraportti 2019.

HELCOM (2018), Thematic assessment of the radioactive substances in the Baltic Sea, 2011 – 2015. Baltic Sea Environment Proceedings No. 151.

IAEA (2005), Environmental and source monitoring for purposes of radiation protection: safety guide, IAEA Safety series standards series No. RS-G-1.8, International Atomic Energy Agency, Vienna, Austria.

Kostiainen, E. and Ylipieti, J. (2010), Radioaktiivinen cesium Suomen ruokasienissä, STUK-A240. Helsinki, Radiation and Nuclear Safety Authority.

Mattila A. and Inkinen S. (ed.) (2019), Environmental Radiation Monitoring in Finland: Annual Report 2018, STUK-B 236. Helsinki, Radiation and Nuclear Safety Authority.

Siiskonen, T. (ed.) (2020), Suomalaisten keskimääräinen efektiivinen annos vuonna 2018, STUK-A263. Helsinki, Radiation and Nuclear Safety Authority.

TVO Teollisuuden Voima Oyj (2020), Olkiluodon ydinvoimalaitoksen ympäristön säteilyturvallisuuden vuosiraportti 2019.

Kainulainen E. (ed.) (2020) Ydinenergian käytön turvallisuusvalvonta: Vuosiraportti 2020, STUK-B 245. Helsinki, Radiation and Nuclear Safety Authority.

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	Power plant releases and nuclear weapons test in the 50's and 60's.	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	$1.248\times10^{+9}$ 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	In maritime and land environment

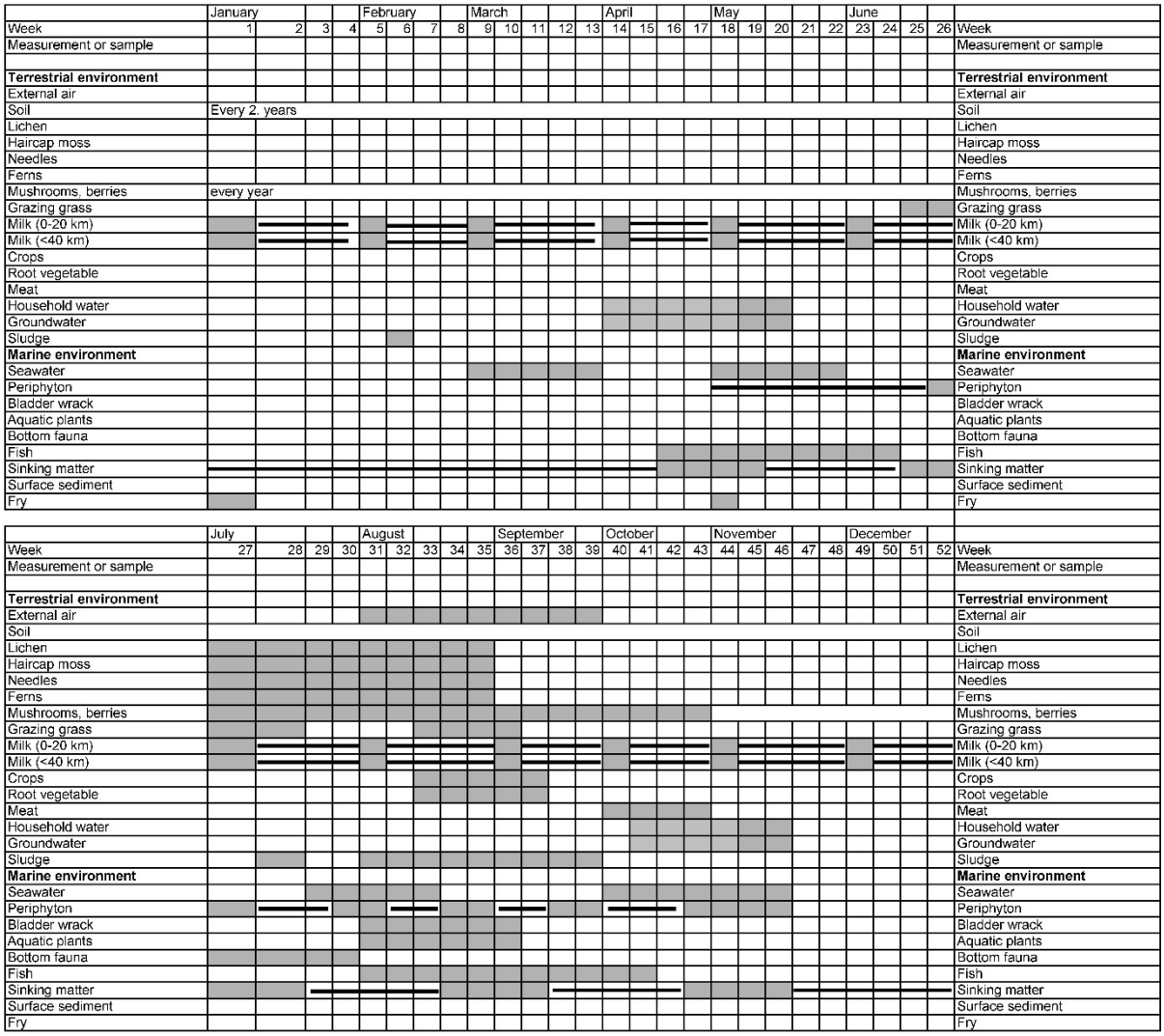
		weapon testing in the 1950s and 1960s	
Ru-103 Ru-106 ruthenium	39 days 372 days	Releases from a power plant or other nuclear facility	In air samples
Ag-110m silver	250 days	Power plant releases	Atmospheric and maritime environment
Sb-124 antimony	60 days	Power plant releases	Atmospheric and maritime 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, Cs-134 a shorter-lived fission product and from power plant releases	Land and maritime environment
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

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 ^{3}H from the closest collector once a month; other gamma emitters and ^{3}H 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 ^{3}H 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 ^{3}H 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 utilized in the production of foodstuffs).		

ANNEX 3 Collection schedule of STUK's monitoring samples



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
Seawater	<20
Benthic fauna	<3.0
Fucus vesiculosus	<20

ANNEX 5 Results of periphyton sample monitoring measurements

Table 19. Results of Loviisa periphyton sample monitoring measurements in 2019. '<MDC' indicates that the activity concentration of the radionuclide is below the specified limit, which for Mn-54 was 0.89 Bq/kg; for Co-58, 1.07 Bq/kg; for Co-60, 0.93–1.2 Bq/kg; for Ag-110 m, 1.1–1.3 Bq/kg; and for Sb-124, 1.05 Bq/kg.

Time	3/4 – 2/5/2019		2/5 – 17/5/2019		17/5 – 14/6/2019		14/6 – 5/7/2019		5/7 – 8/8/2019		8/8 – 12/9/2019		12/9 – 11/10/2019		11/10 – 14/11/2019	
Nuclide	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**	**Bq/kg d.w.**	**±%**
Be-7	337	11	336	11	282	11	242	9	193	17	570	12	530	11	990	15
K-40	630	13	540	15	760	15	880	12	510	24	480	22	470	15	610	22
Mn-54	<MDC		<MDC		<MDC		<MDC		< MDC		2.3	17	1.3	32	<MDC	
Co-58	<MDC		<MDC		<MDC		<MDC		< MDC		1.7	22	1.1	30	<MDC	
Co-60	1.3	58	2.1	24	< MDC		< MDC		< MDC		1.7	16	5.1	16	0.9	34
Ag-110m	<MDC		5.3	17	< MDC		1.3	17	< MDC		15	15	6.9	18	12	19
Sb-124	<MDC		<MDC		<MDC		<MDC		<MDC		3.4	16	1.4	26	<MDC	
Cs-137	120	14	83	10	81	10	53	9	16	24	68	12	109	11	160	

Uncertainty at a precision of 2σ

Table 20. Results of Olkiluoto periphyton sample monitoring measurements in 2019. '<MDC' indicates that the activity concentration of the radionuclide is below the specified limit, which for Cr-51 was 5.0–13.4 Bq/kg; for Mn-54, 0.46–1.1Bq/kg; for I-131, 1.6–4.6 Bq/kg; for Cs-134, 0.9–1.3 Bq/kg; and for Ce-141, 0.6–1.5 Bq/kg.

Time	10/4 – 9/5/2019		9/5 – 7/6/2019		7/6 – 19/6/2019		19/6 – 11/7/2019		11/7 – 31/7/2019		31/7 – 23/8/2019		23/8 – 5/9/2019		5/9 – 26/9/2019		26/9 – 16/10/2019		16/10 – 22/11/2019	
		±%		±%		±%		±%		±%		±%		±%		±%		±%		±%
Nuclide	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**	**Bq/kg d.w.**	**2σ**
Be-7	350	11	168	13	97	14	216	14	142	17	380	10	400	16	490	12	720	11	1,000	11
K-40	560	16	970	13	900	13	880	14	730	22	630	15	390	22	400	18	590	16	560	13
Cr-51	<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		9.7	36	<MDC		<MDC	
Mn-54	1.44	36	1	26	<0MDC		<MDC		<MDC		<MDC		<MDC		1.12	36	<MDC		<MDC	
Co-60	2.4	19	2.2	13	0.78	34	1.15	18	1.79	20	<MDC		1.21	44	8.8	10	8.4	11	2.6	28
I-131	<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		3.0	34	<MDC		<MDC	
Cs-134	<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		0.82	24	<MDC		<MDC	
Cs-137	102	15	79	13	82	18	103	13	31	16	54	10	51	16	59	12	100	15	77	14
Ce-141	<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		<MDC		1.06	38	<MDC		<MDC	

Uncertainty at a precision of 2σ