Recommended practices for radioecological monitoring of the environment

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Abstract. Radioecological monitoring is crucial for observation, assessment and forecast of the impact of radiation factors on people and environment. The analytical paper provides recommendations for the sampling of soil, snow, and vegetation for radioecological monitoring in arctic areas. It also presents different aspects of organizing general assessment of ecological condition in the buffer and control areas. The paper reveals the basic mechanism of radical accumulation in the soil, and radioisotope sorption factors depending on mechanical and mineralogical soil composition and on plant structure.

1. Introduction
The deployment of nuclear energy increases the risk of possible human exposure to ionizing radiation. Radionuclide composition of the biosphere has changed dramatically over the last one hundred years and is still changing due to anthropological activities. Therefore, ongoing radio monitoring of ecosystems is one of the leading parametric criteria of the anthropogenic press in the world.

The years of operation of nuclear fuel reprocessing plants have shown that their emissions into the atmosphere contain such isotopes as $^{14}\text{C}$, $^{129}\text{I}$, $^{131}\text{I}$, $^{106}\text{Ru}$, $^{134}\text{Cs}$, $^{137}\text{Cs}$, about 70% of tritium ($^{3}\text{H}$) and krypton ($^{85}\text{Kr}$). Then they concentrate in the soil and a part of them enters the human body through the food chain. The main radionuclides $^{137}\text{Cs}$ and $^{90}\text{Sr}$ also percolate into the soil and contaminate it.

The techniques of radioecological monitoring are crucial for radiation safety. Its main goal is to obtain objective information on the state of ecosystems and their radiation exposure to radiation-hazardous facilities. The system of monitoring comprises four levels: local, regional, territorial, and global [1].

It is vital to check regularly the sources of pollution, to control air, aquatic ecosystems, soils, residential and public buildings, to monitor people’s health [2].

The ultimate objective of radioecological monitoring is prevention and forecast of the negative impact of radiation factors on public health and environment. In this context, there are standard recommendations for organizing radioecological monitoring:

- make a register of hazardous radiation facilities;
- analyze available and predicted data on discharges and emissions of hazardous radiation facilities;
• determine the level of radioactive contamination of all ecosystems of interest;
• develop regulations for radioecological monitoring of ecosystems during standard and extraordinary operation of a radiation hazardous facility;
• set up a network of stationary control stations that will regularly scan the impact of the radiation hazardous facility on ecosystems and people;
• collect and analyze samples of ecosystem elements within 30 kilometers of radiation hazardous facilities.

2. Materials and methods
Measuring, collecting and analyzing data is a labor-intensive process which requires certain skills. At present, most companies related to radioecology conduct automatic measurements to monitor radioactive pollution of the environment. However, alongside with automatic gauges, a number of measurements have to be performed manually, which determines the accuracy of radioactivity measurement.

Recommendations for soil sampling for radioecological monitoring
Soil is radioactive due to its natural radionuclides ($^{40}$K, $^{238}$U, $^{235}$U, $^{232}$Th and their decomposition products), accumulation of industrial radionuclides during the operation of nuclear power plants, radiation accidents at nuclear facilities, and consequences of nuclear testing in the atmosphere.

Soil samples should not be taken on sandy areas devoid of grass vegetation. The sampling site should be flat, uniform, open. The distance from the surrounding buildings and trees should be at least two times their height.

Before sampling, the level of radiation should be measured at 5-10 cm above the soil. The sampling site should be located at least 20 m away from country roads and railways. Soil samples should preferably be taken with vegetation in autumn from even and only slightly inclined obscure areas, where soil has not been subjected to digging or plowing for 8–10 years. Soil samples weighing 2 kg are extracted from the corners of a square with a 5-meter side, and from its center to a depth of at least 10 cm (so-called “envelope technique”).

This technique can be used only if the radiation value measured directly at the ground level differs from the radiation value measured at the height of 1 m by no more than 1.5 times.

First, the contour of the sample is marked on the ground, then the grass is cut off inside the contour and the sampler is driven into the ground to its full length along the contour. The soil is cut off underneath the sampler with a shovel. The resulting sample block with the sampler is transferred onto a plastic wrap, put into a plastic bag, and labelled. All samples should have labels indicating the exact location of sampling, the terrain relief, the state of the soil surface and vegetation, and the slope ratio.

Then the soil sample is laid out on a PVC plastic tray, the bottom of which is covered with a clean plastic film. A label with the number of the sample is attached to the film. The sample is dried in the open air, stirring occasionally, crushing the lumps and sieving through a sieve with mesh size of 1 mm. Plant residues are separated from the part that did not pass through the sieve and burnt to ash in a muffle furnace at a temperature of 400°C- 450°C. When sifting the sample, stones, roots and other foreign objects are discarded. Ash from the muffle furnace is mixed carefully with the sieved sample and placed in labeled and weighed stainless steel cuvettes for further drying in a drying cabinet at a temperature of 110°C - 120°C during 4 - 5 hours with occasional stirring. Then the sample is cooled and weighed to find the weight of the dry sample.

To find the specific activity of $\gamma$-emitting radionuclides, a counting sample is prepared from the dry sample in a cuvette with a diameter of 25 mm or 61 mm, depending on the content of radionuclides, and sent for measuring in a semiconductor $\gamma$-spectrometer.

Recommendations for vegetation sampling for radioecological monitoring
Vegetation samples are taken together with soil samples once a year in the buffer and control areas in autumn when the flowering period has finished. Vegetation samples are taken in the same places as soil samples. The grass is cut down with a sharp knife. At least 3 cm of plants should be left above the ground. The selected mixed sample should weigh about 2.0 kg. Mixed samples of vegetation are
placed in large plastic bags labeled with the number of the sample and the exact location of sampling (the number of vegetation sample should match the number of soil sample).

The grass sample is pre-dried in the open air to a light dry state. Then it is weighed and placed in a stainless steel cuvette, covered with a lid and put into a drying cabinet to turn to ash by a flameless technique with occasional stirring.

The ash sample is put into a labeled and weighed porcelain cup and placed into a muffle furnace at a temperature of 400 - 450°C to obtain the constant weight of ash. After cooling, the burnt residue is weighed and triturated in a mortar to obtain a homogeneous mass.

A “thin layer” counting sample is prepared from the burnt residue to measure the total β-activity. To this end, 100 mg of the burnt residue is applied on an aluminum base of 18 mm in diameter. The residue is moistened with 5 drops of ethanol, distributed evenly over the surface of the base, dried under a thermal lamp, and sent to measure the total activity of β-emitting radionuclides.

To find the specific activity of γ-emitting radionuclides, a counting sample is prepared from the burnt sample. To do this, a sub-sample of the burnt residue is placed into a labeled and weighted cuvette of 61 mm in diameter, weighed to determine the mass of the burnt sample in the counting sample, and sent to a semiconductor γ-spectrometer for measuring.

Recommendations for snow sampling for radioecological monitoring

Snow sampling is carried out at the same control points where samples of vegetation and soil are taken, away from highways and railways. To make a composite sample, they put together five samples which have been taken in the center and at the corners of a square with a 10-cm side, as deep as the snow cover. The lower layer of each sample is carefully cleaned of soil, leaves, and other inclusions. A metal cylindrical sampler with sharp edges and the internal diameter of about 80 mm is used for sampling. Snow samples should be taken to the full depth of the snow cover. Each composite sample is placed in a labeled plastic bag.

In the laboratory, the snow sample is acidified with hydrochloric or nitric acid and left until the snow melts. Snow melt water is poured through a sieve into heat-resistant bowls using a porcelain mug and a funnel. The sample is evaporated to a volume of approximately 100 ml and the entire sample is transferred to a weighed labeled porcelain dish. The inside of the bowl is rinsed with a solution of hydrochloric acid. Rinse waters are incorporated into the sample. The whole sample is evaporated to dry condition, burnt to ash on an electric stove and heated in a muffle furnace at a temperature of 400 - 450°C for six hours. Then it is cooled and weighed to find the mass of the burnt residue. A “thin layer” counting sample is prepared from the burnt residue to measure the total β-activity. To do this, 100 mg of the burnt residue is applied on an aluminum base of 18 mm in diameter. The residue is moistened with 5 drops of ethanol, distributed evenly over the surface of the base, dried under a thermal lamp, and sent to measure the total activity of β-emitting radionuclides.

After measuring, the residue is scraped off the substrate and incorporated with the rest of the burnt residue into a labeled and weighed polyethylene cuvette of 61 mm in diameter. The sample number is indicated on the cuvette. The burnt residue is compacted with a pestle, weighed to find the burnt residue mass in the counting sample, and sent to a semiconductor γ-spectrometer for measuring.

The method is based on comparing the counting rate of the sample with certified values of activity and calculating the total β-activity of the sample.

3. Results and discussion

Radioactivity of environmental samples in radiometric analysis is usually estimated or measured using α- and β-radiometers. The main characteristics of a radiometer is the sensitivity of the instrument, which mainly depends on the radiation background of the installation itself and on the detection efficiency of the detecting unit. The radiometer sensitivity determines the minimum detected activity.

To measure the total α- and β-activity of the counting samples obtained by selective radiochemical extraction methods (dry residues of soil, snow and vegetation samples), α- and β-radiometers are preferable when measuring trace-level activities. Confidence level of the research should be at least
95%, error of determining $\alpha$-$\beta$-active substances in dry residues at a radiological complex should be $\leq$5%.

Highly water-soluble isotope $^{90}$Sr gets into calcium-loving leguminous plants relatively quickly, but is absorbed by soil, root plants and grain crops to a smaller degree. It has been noted that less acidified soils reduce the rate at which radionuclides get into plants. When analyzing soil samples, the following can be taken into account: according to the degree of reduction of cesium accumulation in the crops, the soil types are arranged in the following sequence: sod-podzolic sandy-loam soil, sod-podzolic loamy soil, gray forest soil and black soil.

The smaller the dispersed fraction of soil, the better it absorbs radionuclides, therefore, the highest concentration of radionuclides is noted in bottom sediments and silt. The rate of penetration of radionuclides into the soil is also determined by precipitation. It has been found out that $^{90}$Sr, once it has fallen on the surface of the soil, is washed down by rain into its deeper layers, while the main part of most other radionuclides stay in the layer up to 5 cm deep. It should be noted that radionuclides contained in water could be divided into two groups according to their origin: the first includes radionuclides that have existed since the formation of the Earth as a planet; the second contains those constantly appearing from natural nuclear transformations.

4. Conclusions
The main mechanism of absorbing radicals in the soil is ion exchange. Radioisotopes sorption depends on mechanical and mineralogical composition of soil. Accumulation of radionuclides by plants and their amount can fluctuate considerably and largely depends on biological characteristics of plants and the pH of the soil. Primordial radionuclides belong to families $^{238}$U, $^{235}$U and $^{232}$Th and to the group of dispersed terrigenous radionuclides. The main representative of the last group is $^{40}$K, which is present in all structures of the biosphere in relatively large concentrations.

The Russian nuclear industry is one of the most advanced in the world in scientific and technical developments in the field of reactor design, research and the use of nuclear fuel [3; 4]. Russian experts make extensive use of nuclear energy in the Arctic and can share their experience.

Systematic and timely radioecological monitoring is an overriding priority in the use of nuclear energy in the world. Concern for the environment and human exposure is of prime importance [5; 6].

At present, the use of nuclear energy on the Kola Peninsula has not had a significant impact on the environment yet. This is proved by accurate annual data of the measured level of radionuclides in soil, snow, and vegetation samples. They are lower than background values stipulated by Russian standards. Radionuclides are often difficult to detect even when using highly sensitive instruments. Regular monitoring of human activities in the nuclear sector contributes not only to ensuring the safety of the environment, but also allows to organize sanitary and epidemiological measures to minimize the impact of the anthropogenic factor on the health of residents of the North in general [7; 8].

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