

INVESTIGATION OF REDISTRIBUTION OF ARTIFICIAL (^{137}Cs , ^{90}Sr) AND NATURAL (^{40}K) RADIOISOTOPES IN DIFFERENT USAGE SOILS

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Abstract. In this study we investigated artificial (^{137}Cs , ^{90}Sr) and natural (^{40}K) radioisotopes' vertical distribution in different usage soils. Soil samples were collected in Lithuanian territory, which was, after the nuclear weapons and the Chernobyl Nuclear Power Plant (ChNPP) accident, contaminated with artificial radionuclides. For the study, three places were selected, taking into account human activities and radioactive environmental contamination (Neris Regional Park, a field near the Ignalina nuclear power plant and a field in a village in Ukmergė district). In addition, we analysed the soil organic matter, which determines the amount of nutrients, water infiltration, ion exchange, adsorption of pollutants. Studies show that in those places the predominant soil type is sandy loam, with soil mineralization rate close to 1. In the village place and the regional park place (respectively Jogvilai and Paaliosė areas), ^{137}Cs specific activity decreases exponentially. However in the village place (Paaliosė), at 10-15 cm soil depth, there is a noticeable increase in the specific activity of ^{137}Cs , associated with the former nuclear weapons test contamination. ^{40}K changes the specific activity of the soil samples taken from the depth in all areas. In the village place (Paaliosė), and the field near the Ignalina nuclear power plant (Stabatiškės), ^{40}K specific activity decrease with the increase of depth was observed, and in the field in the village in Ukmergė district (Jogvilai) it was vice versa – with the increase of depth, ^{40}K specific activity increases. The average ^{90}Sr radionuclides in the soil are $6,4 \pm 1,1$ Bq/kg (in the village place (Paaliosė)) $6,4 \pm 2,0$ Bq/kg (field near Ignalina nuclear power plant) and $11,3 \pm 1,7$ Bq / kg (the field in the village in Ukmergė district).

Key words: ^{137}Cs , ^{90}Sr , ^{40}K , soil

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1. INTRODUCTION

Artificial radionuclides, such as ^{137}Cs and ^{90}Sr , are caused in the environment by human activity. Soil is contaminated with the artificial radionuclides together with the fallouts; furthermore, they enter with the falling canopy elements; moreover, they are washed from the tree trunks and branches. It is possible that the secondary environmental pollution is a result of burning forests that are already contaminated with radionuclides, or falling to the ground from elevated dust. Once they reach the surface of the soil, radionuclides migrate deeper. In the process of the soil diffusion, radionuclides migrate vertically: the convection transfers radionuclides from the soil into plant root systems [1] – [4].

The migration of radionuclides in the environment depends on the physico-chemical properties, climatic conditions, environmental terrain, soil type, hydrological regime of the territory, vegetation type, agrochemical and agricultural features and other factors [5].

Redistribution of radionuclides in the soil is, further, the result of human activities. The redistribution can be of different types depending on

the area: forest, location of intensive agricultural activity [5].

The aim of this article is to evaluate the vertical distribution of the artificial (^{137}Cs and ^{90}Sr) and natural (^{40}K) radionuclides in the soil, depending on different types of human activity.

2. EXPERIMENTAL DETAILS

The main source of Lithuanian soil pollution with the artificial radionuclides (^{137}Cs , ^{90}Sr) is the nuclear testing and nuclear power plant accidents (Chernobyl, Fukushima NPP). The soil contamination by these radionuclides is characterized by discoloration.

In this study, three locations (Figure 1) have been selected for examination, all characterised by human activities and radioactive environmental contamination (Neris Regional Park, a field in the vicinity of the Ignalina nuclear power plant and a field in a village in Ukmergė district).

Neris Regional Park soil has been contaminated with radionuclides by nuclear tests and the Chernobyl NPP disaster. Further contamination has been driven

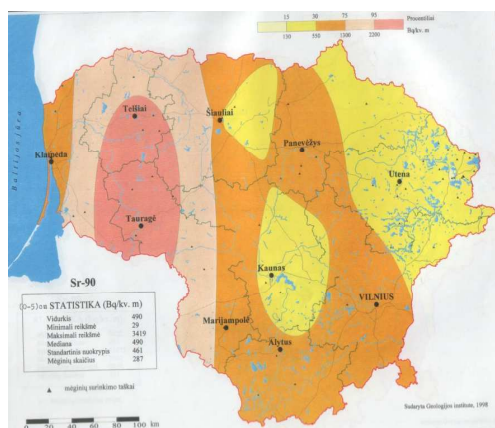
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by the nature of Scots pine (*Pinus sylvestris* L.) roots, when the agricultural soil remained undisturbed.

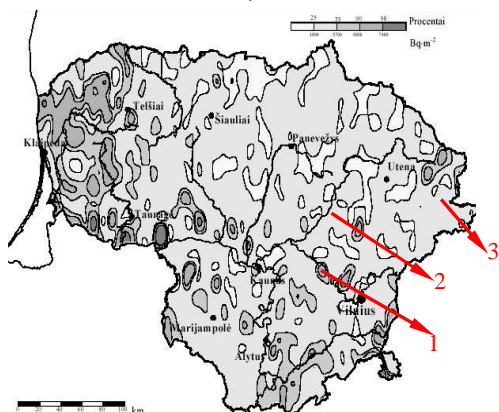
Stabatiškės field near the Ignalina nuclear power plant area was polluted during the Chernobyl NPP accident; later on, the Ignalina NPP was the possible localized source of pollution in this field. Soil in the field was used for agricultural purposes in the time of ChNPP catastrophe, while in more recent times it was in the Ignalina NPP construction zone of influence.

Jogvilai field in Ukmergė district is a part of the communal garden, which has been cultivated and affected by tree roots (mostly apple tree).

Lithuanian soil contamination by ^{137}Cs and ^{90}Sr (a) after the ChNPP accident and study sites (b) are displayed in Figure 1 [6].



a)



b)

Figure 1. Distribution of ^{137}Cs and ^{90}Sr activity density in the soil after the Chernobyl NPP accident in Lithuania [6] and research sites Layout 1 - Neris Regional Park at Paaliosė, 2 - Jogvilai field in Ukmergė district at, 3 - Stabatiškės field near the Ignalina nuclear power plant

The dominant soil type in research sites is sandy loam. Soil samples were collected by a metal ring. Ring diameter - 16 cm and height - 5 cm. The ring is hammered to the soil then the bottom of the ring is covered with a trowel and the sample is lifted. For the collection of the soil samples, up to 30 cm deep area is excavated, and the soil samples are collected every 2-5 cm to 10 cm depth and 10-30 cm depth on every 5 cm.

A radiometric analysis of soil samples was done by the procedure described in [7].

The organic matter determines the peculiarities of the soil: nutrients, water infiltration, ion exchange, adsorption of the contaminants and others. The soil organic matter was evaluated by the method described in [8].

Mineralization of the soil is one of the factors determining the radionuclides in the soil to be agile. In this study, mineralization of the soil has been assessed by the methodology described in [7].

The relation between the radionuclide concentrations in the soil and organic matter was assessed by analysing the correlation coefficients [10].

3. RESULTS AND DISCUSSION

The research results showed that soil acidity from the Stabatiškės field near the Ignalina nuclear power plant and the Jogvilai field in the Ukmergė district was close to 7 pH, while in the Paaliosė field, the soil was at moderate acidity (pH = 4.7). It is worth noting, at the sites where the human activity is minimal, the soil is acidic. This could be linked to the global environmental acidification wherein the gardening and horticulture activities require fertilizers and other materials (such as wood ash to reduce the acidity of the soil, as well to fertilize it) modify soil pH.

Sandy loam soil dominates in all three investigated sites. Soil salinity ratios in these sites are close to 1. The highest factors of the soil mineralization were determined in the Paaliosė field (Neris Regional Park). Taking into account the authors' [11] ideas, it is likely that ^{137}Cs specific activity in the plants taken from the site could be higher than in the other sites of the study.

The average values of organic matter are different below the surface (0-25 cm). The difference is most striking in the upper layers of the soil. This could be linked to different anthropogenic nature of the activity: the forest in the Paaliosė field (Neris Regional Park), community gardens in the Jogvilai field (Ukmergė district) and the glade in the Stabatiškės field near the Ignalina nuclear power plant. The variation of organic matter (OM) by the soil depth in investigated sites is shown in Figure 2.

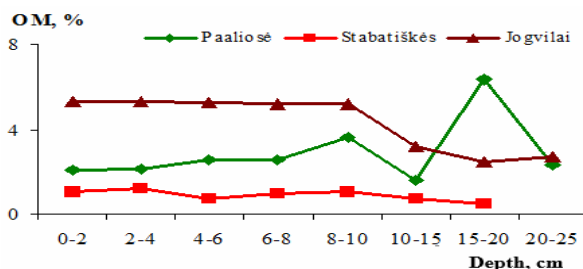


Figure 2. Distribution of organic matter in different soil layers

The change of organic matter (OM) according to depth is extremely uneven in the Paaliosė research site (Neris Regional Park). The increase of the values in organic matter was observed from 8-10 cm to 15-20 cm depth and is related to the influence from the tree root system, particularly evident at 15-20 cm depth - in the depths of the largest Scots pine root biomass (27%). In other investigated sites, the variation from the influence of the tree root biomass on OM values is not

so significant. In the Stabatiškės field near the Ignalina nuclear power plant, a large increase is observed in the OM at 2-4 cm soil layer, in the area of grassy vegetation abundance might have had greater importance than grew tree (*Pinus sylvestris* L.) root system. If we ignore the amount of OM at 0-2 cm soil layer, we can detect that organic matter has the highest percentage at 0-15 cm layer from the Jogvilai field (Ukmergė district) soil, and the change is the most stable. This change of OM values can be explained by gardening and the distribution of the apple tree root system that has grown in the soil depth.

From the results of correlation between the OM and artificial radionuclides' (^{137}Cs and ^{90}Sr) specific activity in the soil, we can claim the relationship between ^{137}Cs and OM is strong only at the Paaliosė field (Neris Regional Park), where the correlation coefficient is calculated to be 0.73; at the Jogvilai field, the correlation coefficient is 0.96. The results of this correlation analysis have shown that the correlation between ^{90}Sr specific activity and organic matter in the soil at 2 of 3 sites is low or questionable (correlation coefficients: -0.42 and -0.1).

Variation of ^{137}Cs specific activity is presented in Table 1.

Table 1. Variation of ^{137}Cs specific activity

Deep, cm	^{137}Cs specific activity, Bq/kg		
	Paaliosė field (Regional Park)	Stabatiškės field (vicinity of the Ignalina npp)	Jogvilai field (village)
0-2	15,6±2,3	9,4±1,0	8,6±3,6
2-4	51,3±3,2	4,8±0,5	8,9±2,6
4-6	13,2±2,3	5,1±1,5	8,4±3,3
6-8	12,1±3,0	6,7±2,0	7,8±4,9
8-10	8,7±1,8	8±0,7	7,5±4,3
10-15	16,2±5,8	10,8±1,8	5,8±2,4
15-20	0,2±0,1	9,3±1,3	3,9±1,4

The highest specific activity of ^{137}Cs from the soil samples was determined at the Neris Regional Park at the Paaliosė habitat while the lowest was at the Jogvilai habitat in the Ukmergė district.

^{137}Cs distribution in the soil according to its depth in all three locations is distributed differently. The increase of ^{137}Cs specific activity at Paaliosė (Neris Regional Park) and at the Stabatiškės field near the Ignalina nuclear power plant is observed at 10–15 cm depth. At this soil depth, ^{137}Cs specific activity increase has been observed in other sites as well [12]. It is associated with global radionuclide fallout, which is due to nuclear weapon tests. At the Jogvilai field in the Ukmergė district, this phenomenon is not expressed. This might stem from a number of reasons. Particularly, it can be related to soil fertilization and arable soil layer intensive remix in community gardens. Different initial soil surface layers of radioactive contamination took place in a variety of past periods. ^{137}Cs specific activity in the Neris Regional Park at the Paaliosė site had a significant increase at 2–4 cm soil layer depth. This vertical distribution of ^{137}Cs in the soil

is only possible when the area is not disturbed by any agricultural activities after the contamination. Vertical distribution of ^{137}Cs in the soil of Lithuanian territory is presented in [10] and it is comparable with the Paaliosė site in the Neris Regional Park.

^{137}Cs specific activity in the soil is almost unchanged up to the depth of 10 cm at the Jogvilai field (community garden area). This is the consequence of intensive agricultural activity; at this depth, soil was dug and mixed.

Soil pollution by ^{90}Sr in Lithuania was negligible (increased 1.1 times) after the Chernobyl nuclear power plant accident. Variation of ^{90}Sr specific activity is presented in Table 2.

Table 2. Variation of ^{90}Sr specific activity

Deep, cm	^{90}Sr specific activity, Bq/kg		
	Paaliosė field (Regional Park)	Stabatiškės field (vicinity of the Ignalina npp)	Jogvilai field (village)
0-4	17,0±0,9	3,2±1,3	15,3±1,1
4-8	17,6±0,8	18,2±0,7	13,7±2,5
8-12	6,7±1,0	6,4±1,2	12,5±1,9
12-16	4,7±1,2	2,1±0,8	11,2±1,4
16-20	5,6±1,1	2,2±0,9	16,5±3,8

In the areas where human activity is minimal, such as a forest (Paaliosė field) and a meadow (Stabatiškės field), we determine the maximum of ^{90}Sr specific activity up to 8 cm deep and 8 cm from the observed decline. In the Jogvilai research site, the area where the intensive gardening takes place, this radionuclide change is similar to that of ^{137}Cs – ^{90}Sr radionuclides in the soil, since it is almost unchanged up to 10-15 cm depth.

Potassium is an important macronutrient for the support of plant growth. It is responsible for osmotic pressure adjustment and leads to cell growth in the plants. Up to 4 percent of the non-radioactive form of potassium in soil is ^{40}K , which is a chemical analogue of ^{137}Cs . When there is a lack of potassium in the soil, the plants also absorb other monovalent ions such as caesium [13]. Variation of ^{40}K Specific activity is presented in Table 3.

Table 3. Variation of ^{40}K specific activity

Deep, cm	^{40}K specific activity, Bq/kg		
	Paaliosė field (Regional Park)	Stabatiškės field (vicinity of the Ignalina npp)	Jogvilai field (village)
0-2	752±70	550±61	410±72
2-4	560±35	590±53	390±59
4-6	590±40	613±172	530±43
6-8	585±41	403±38	725±34
8-10	520±49	598±59	740±37
10-15	290±30	349±42	769±43
15-20	312±37	395±37	812±54

The change of ^{40}K specific activity in soil samples, with the depth in all habitats, is more even than ^{137}Cs . In the Neris Regional Park at the Paaliosė field and in a field near the Ignalina nuclear power plant at the Stabatiškės field, a decrease in the radionuclide specific activity with the increase of depth has been observed and at the Jogvilai field (Ukmergė district the inverse phenomenon has been observed – an increase in ^{40}K specific activity with the increase of the depth. This phenomenon can be explained by various human activities.

4. CONCLUSIONS

- ^{90}Sr highest specific activity values have been investigated in places where human activity minimal set is up to 8 cm depth and 8 cm from the observed decline.
- ^{90}Sr specific activity in soil results reflect the natural vertical migration processes of radionuclides in the soil at research places where farming is not disturbed by processes of nature or it is changed minimally.
- ^{137}Cs specific activity values decrease exponentially; however, at 10-15 cm depth in the Neris Regional Park at the Paaliosė field there is a noticeable increase in the specific activity of ^{137}Cs , associated with this radionuclide on global fallout, which is due to nuclear weapon tests. This phenomenon has not been observed in other research places.
- The relationship between ^{137}Cs specific activity in soil and OM is strong only in a regional park (correlation coefficient is 0.73) and garden community (correlation coefficient is 0.96).
- The relationship between ^{90}Sr specific activity in soil and OM in 2 out of 3 sites is low or questionable (correlation coefficient varies from 0.42 to -0.1).

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