Vertical Distribution of Cs-137 in Soils of Orel Region 30 Years after Chernobyl Accident

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Abstract. The article presents the first results of the study of vertical redistribution of Radiocaesium in different types of agricultural soils of the Orel region, performed in the period 2016-2017. Orel region, one of the 19 regions of Russia, where as a result of the Chernobyl accident (1986) large areas were contaminated with various radionuclides, including Cs-137, with soil contamination level Cs-137 above 1 Ki/km\textsuperscript{2} (37 kBq/m\textsuperscript{2}). The work was carried out as a private initiative study within the field teaching and scientific practice of the Ecology Faculty of the Peoples’ Friendship University of Russia (RUDN). It was found that the main stock of Radiocaesium falls on the top 20 cm of arable soils. Despite the overall reduction in dose over 30 years, Radiocaesium is still traceable to a depth of 40-50 cm, depending on soil type, organic matter content, particle size distribution and other factors.

1. Introduction
As a result of the Chernobyl accident (1986), about 520 dangerous radionuclides and 190 tons of radioactive substances were released into the atmosphere (The Chernobyl accident and its consequences…, 1986). Radionuclides released after the accident into the atmosphere fell to the earth's surface and accumulated in the soil, and were included in biogeochemical migration cycles (Askarova, D.A., Glebov, V.V., Rodionova, O.M., Anikina, E.V., 2019). As a result of movement in the soil and subsequent root absorption, radionuclides enter parts of plants that are of food or feed value (Rakhimova et al. 2015). Radioactive contamination caused morbidity in the European part of the country (Glebov V.V., Rodionova O.M., Anikina E.V., Pitkevich M. Yu., Kulieva G. A., Mikhailichenko K. Yu., 2017).

The main dose-producing radionuclide in most Chernobyl areas was Radiocaesium (Cs-137). Total Radiocaesium emission was estimated at 8*10\textsuperscript{16} Bq of which in Russia-30%

Areas with the level of soil contamination with cesium-137 above 1 Cu/km\textsuperscript{2} (37 kBq / m\textsuperscript{2}) were found on the territory of 19 regions of Russia, but the most contaminated are four of them: Bryansk (11.8 thousand km\textsuperscript{2} of contaminated areas), Kaluga (4.9 thousand km\textsuperscript{2}), Tula (11.6 thousand km\textsuperscript{2}) and
Oryol (8.9 thousand km²) (Vavilova V. M., Terekhova V. A., 2009; Kochetkov P. P., Malysheva A. G., Glebov V. V., 2017).

The study of migration of radionuclides in the upper soil horizons of agricultural lands is one of the important approaches to assessing their potential for entry into food or feed (Rodionova, O.M., Chernykh, N.A., Glebov, V.V., Shamsher, A.M., Baeva, 2019). Migration of radionuclides along the soil profile occurs due to the movement of soil particles, in which they are included, due to the movement of soil moisture containing soluble and colloidal forms (Silantyev A. N., 1989).

In the Orel region, 22 of the 24 administrative districts with a population of about 350 thousand people living in more than 2 thousand settlements were exposed to radioactive contamination as a result of the Chernobyl accident. The radioactive cloud covered almost 40 percent of the territory of the region, agricultural lands and forest Fund of the region were significantly affected. Most severely were affected by radioactive contamination following areas: Bolhovskogo, Sverdlovsk, Dmitrov, Malo-Arkhangelsky (Atlas of radioactive contamination of the European…, 1998).

The aim of the work was to determine the change in the vertical redistribution of Cs-137 in the soils of agricultural landscapes, in connection with ongoing agricultural activities.

When choosing the survey areas, the data of the center for hygiene and epidemiology in Orel region were used for the average annual effective radiation doses of the population of 900 settlements of the region. It was found that in more than 700 settlements belonging to the zones of radioactive contamination, the gamma background almost corresponds to the natural one that existed before the accident. The positive dynamics of decrease in the levels of background radiation in the most contaminated districts of the region (Bolhovskogo, Sverdlovsk, Dmitrov, Malo–Arkhangelsky, etc.), which recorded relatively high rates of gamma – ray background (up to 120 – 150 Mkr/hr).

Brief description of the soil cover of the research area. Orel region is located in the areas of deciduous forests and forest-steppe. However, currently, forests (oak forests, pine forests and secondary summer, mainly birch) occupy only 10% of its territory. The soil cover of the region is dominated by black soil (typical, leached and podzolic), occupying more than 52% of its area. Grey forest soils (including dark grey) account for 34% of the land. The remaining 14% are sod-podzolic soils (The center of hygiene and epidemiology in the Orel region).

For particle size distribution in all categories of land dominated by heavy loam (1046.7 thousand hectares or 51.0 %), loam (168.2 hectares or 34.4%) and sandy loam. The presented soils occupied 1.3% of the agricultural land.

2. Materials and methods
Field sampling was carried out in the summer (July 2016 and 2017), in operating or abandoned farms of settlements of the Oryol region. The location of the sampling site in 2006 was established using GPS Garmin 62stc. Soil sampling was carried out at 3 (2016) or 5 (2017) points (envelope method or diagonal "envelope": a point in the center and two in the upper and lower corners of the site). The coordinates of all points were determined and recorded using GPS.

At each point, the der (exposure dose rate) was measured at a height of 10 cm and 1 m from the soil surface, at the sampling points. Measurements were carried out by a dosimeter (DKG-02U, Arbiter).

Soil samples were taken in 2016, in layers every five centimeters, as in 2006, in three of the five points of each site, diagonally. For soil sampling, sections of 20x50 cm in size and 50 cm in depth were laid and samples were taken along the front wall by a ring with a diameter of 20 cm. The thickness of the layers selected for radiometric analyses was determined by the thickness of the ring and was 5 cm. In 2017, samples were taken with a shovel from the selected genetic horizons of the layered profiles and layered-upper 0-10 cm and a layer of 20-30 cm.

Simultaneously with soil samples, vegetation samples (leaves, grass, cereals, needles, cones) were taken to determine the transition coefficient (CP) Cs-137 to plants.

Soil samples were taken in accordance with GOST 17.4.3.01-83 [4], by the "envelope" method with a side of 100 m, a sampler with a diameter of 20 cm to a depth of 0-0.1 m. the power of the exposure dose was Measured at a height of 0.10 m and 1 m from the ground surface, 5 measurements
were carried out at each point. Also, in order to study the distribution of radionuclides in the soil profile, soil layers with a depth of 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm, 40-45 cm, 45-50 cm were selected (Methods of radiation control, 2000).

Samples of vegetation were selected in accordance with GOST 27262-87 "Feed of plant origin [5-7]. Sampling methods", on 8 plots of 1-3 m², located diagonally. From each plot were selected 300-500 g were prepared and combined sample, from which were selected the average sample weighing 1 to 1.5 kg. for a detailed analysis of a selected cereals wheat, moss, pinecones, pine needles, bark, aspen leaves and litter (Israel et al, 2000).

3. Results and discussion

As a result of field expeditionary research, soil and vegetation samples were selected, the value of der was measured (table. 1).

| Soil type                              | Populated   | Number of soil samples | MED, 2016 - 2017  |
|----------------------------------------|-------------|------------------------|-------------------|
| Sod-podzolic, sandy                    | Vasilievskoe | 10                     | 89, 7 ± 16,6      |
| Gray forest and dark gray forest soil  | Domnino     | 10                     | 52, 6 ± 9,3       |
| Typical and leached black soil         | Korovn’yak  | 10                     | 25± 7,4           |

It was found that in almost all areas of the region the der of gamma radiation on the ground is 10-20 µr / h (which corresponds to the background values of the dose rate on the ground before the accident [6]), except for the most polluted areas. The content of Cs-137 in the soil in the sampling areas was also within the norm, except Zalegoschensky and Bolkhovsky areas; there was still some excess of the permissible concentration.

The distribution of Radiocaesium reserves in the top 40 cm of the surveyed soils also showed high variability of its reserves within the site of 100 by 100 meters.

Along with the study of the surface distribution of radionuclides, the study of vertical migration of radionuclides [1] along the profile is of great importance. The sections laid down by us in 2016 – 2017 to a depth of 50 cm were divided into separate layers with a capacity of 5 cm. Further, the content of 137Cs in individual layers of sections was determined by gamma-spectrometric analysis. According to the analysis, graphs of the 137Cs radiation activity dependence on the layer depth were plotted (Vavilova, Terekhova, 2009).

Most of the Cs-137 is concentrated in the topsoil (Fig.1). At the same time, in the vertical distribution of Radiocaesium there is a clear tendency of a sharp decrease with a depth of 15-20 Bq / kg at a depth of 50 cm, regardless of its content in the upper horizons (varying widely from 30 to 160 Bq/kg in the upper 10 cm).

Another characteristic feature is the presence of the second peak of Cs-137 observed at depths from 30 to 45 cm, smaller than the peaks in the upper 15-20 cm. Obviously, it is not possible to explain this by vertical migration alone. Apparently, deep plowing and the formation with subsoil sole cause here a geochemical barrier.

In the Eastern regions of the region (village Droskovo) revealed the smallest of the surveyed values of contamination with Radiocaesium (20.58 Bq / kg), and its sharp decrease with depth, up to background values (at a depth of 30-35 cm).

The highest values (84.36 Bq / kg) were observed in the Western regions of the Orel region (Lubyanka village). A gradual decrease in Radiocaesium with depth here, is replaced by growth at a depth of 40-45 cm, which may correspond to the location of the plow sole (soil compaction).

In the area of the capital of the region (Domnino village, Oryol district), a gradual decrease in the density of contamination with cesium-137 with increasing soil depth is characterized by cyclical, with pronounced peaks at depths of 25, 35 and 50 cm.
In the southern, most polluted areas (Krasnaya Slobodka village) with relatively low pollution density (54.37 Bq/kg at the surface), it is characterized by almost uniform distribution to a depth of 50 cm, with peak values exceeding its content on the surface (Fig. 2).

**Figure 1.** Vertical distribution of $^{137}Cs$ in soil, Bk / kg
(a) Domnino; b) Droskovo

**Figure 2.** Vertical distribution of $^{137}Cs$ in soil, Bk / kg
(a) Lub'yanka; b) S. Krasnaya Slobodka
These results do not contradict previous studies of Radiocaesium migration in the soils of Bryansk and Tula regions [2,10].

The transfer coefficient of radionuclides in vegetation: Droskovo (bark) – 1.1; Droskovo (moss) is 13.5. Technogenic radionuclides were found in other vegetation samples. In Krasnaya Slobodka, the excess of Cs-137 content in the forest litter over the background was detected.

4. Conclusion
As a result of the conducted researches it was established that practically in all areas of the region the power of exposure dose of gamma radiation on the district makes 7-21 μr / hour that corresponds to background values of dose rate on the district before accident.

In most areas, the level of background radiation does not exceed the permissible limits, and in the most radioactive contaminated areas of the region there is a tendency of its decline.

It was found that although the dose of contamination was limited by primary deposition without connection with the surface, however, the further behavior of radionuclides was largely determined by the characteristics of the soil cover. This was obvious on adjacent sites experimental fields (gray forest soil depth 0-5 cm) of the village of Domnino and (on sod-podzolic sandy soils - depth of 0-5 cm) the village Vasilevskoe of Dmitrov district.

Economic activity also has a significant impact on the redistribution of radionuclides. This is evidenced by the profiles of vertical redistribution of Radiocaesium in the village of Domnino (gray forests, cattle pastures) and the village of Droskovo (black soil, arable land).

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Acknowledgments
This paper was financially supported by the Ministry of Education and Science of the Russian Federation on the program to improve the competitiveness of Peoples' Friendship University of Russia (RUDN University) among the world's leading research and education centers in the 2016-2020.