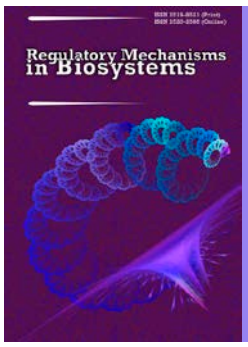

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Radiomonitoring of plant products and soils of Polissia during the long-term period after the disaster at the Chornobyl Nuclear Power Plant

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The article highlights the consequences of the Chernobyl disaster. Northern Polissia has been and still remains the most polluted area. Full scale and limited economic activity is carried out on part of the contaminated territories. The zone of radioactive contamination includes half of the territory of this region, one third of the agricultural land and almost the same amount of the arable land. 9 districts, 734 towns and villages are located within the zone of radioactive contamination. In the long-term period after the disaster the situation in the contaminated areas has improved and become predictable due to natural processes of recovery and implementation of countermeasures based on results of monitoring. However, until today regions of Ukrainian Polissia continue to produce agricultural products which do not meet the requirements of government regulations concerning the content of radionuclides in food and appear to present a threat to consumers. To assess the accumulation of ^{137}Cs in plant products, we investigated the activity of these radionuclides in potatoes, vegetables, root crops and grains, and calculated the ratios of its transition from the ground to the products, which helped evaluate the intensity and amount of accumulation of radionuclides during the completion of the half-life period of ^{137}Cs and evaluate the radiological situation in the northern regions of Polissia. The density of soil contamination with ^{137}Cs and its specific activity in plant products grown on private plots were studied in three different districts of Zhytomyr region: Narodychi, Korosten and Ovruch. Analysis of the density of soil pollution with the ^{137}Cs isotopes in the northern part of Zhytomyr region in the post-disaster period shows that even 30 years after the tragedy, significant areas of arable land under certain conditions remain potentially dangerous on account of contaminated plant products. The specific activity of ^{137}Cs in plant products grown on private plots was studied in residential places where soil contamination was detected. In particular, the list of studied crops included: potato tubers, white cabbage, fresh tomatoes, table beets, carrots, onions, beans, oat grains, corn grains. The most critical were populated areas located in zone II – village Vystupovychi of Ovruch district, village Loznytsia and village Khrystynivka of Narodychi district. In these settlements an excess of DR-2006 in plant products was noted despite the fact that an excess over the maximum permissible level of density of soil pollution was not observed. In decreasing order by the amount of CT ^{137}Cs, we ranked crops as follows: beans > table beets > carrots > potato tubers > corn grains > oats grains > white cabbage > onions > fresh tomatoes. For the population living on radioactively contaminated territories, plant products grown on private plots have been and still remain the main source of ^{137}Cs radionuclides entering the body.

Keywords: radionuclides; contamination; radioactive; rural population; agriculture

Introduction

As a result of the Chornobyl disaster, a significant amount of territory in Belarus, Russia, Ukraine, and Western Europe, especially Scandinavia and the Alpine region, suffered severe contamination (Handl et al., 2003, Michel et al., 2015). The consequences of the Chernobyl disaster have been eliminated over 30 years, however, the process of understanding and generalization of the results of research is still ongoing (Zablotska, 2016).

Virtually the whole territory of Ukraine was, to a greater or lesser extent, exposed to the consequences of the Chornobyl disaster (Evangeliou et al., 2016, Maringer et al., 2017). The most contaminated territory is northern Polissia, and some of its parts (first of all, the Chernobyl zone) are so polluted that any economic activity and residence are prohibited there. In a part of the contaminated territories there is full-scale or limited economic activity. Zhytomyr region was one of the first to feel the consequences of the accident. The most significant radioactive traces were found in the northern districts of the region. The zone of radioactive contamination includes half of its territory, one third of the agricultural land and almost the same amount of arable land. The contamination area of ^{137}Cs over 37 kBq/m^2 (>1.0 Cu/km^2) amounts to 977.6 thousand hectares. 9 districts and 734 settlements where 386.3 thousand people lived were included into the zone of radioactive contamination. Up to the present, quite a large amount of research has been conducted on the study of the migration of ^{137}Cs into facilities of agricultural production, their accumulation in plant products and the evaluation of the effective dose of radiation for local inhabitants (Michel et al., 2005, Michel et al., 2015). The focus is on ^{137}Cs, which is the main dose-forming radionuclide (Goulko et al., 1998; Dancause et al., 2010).

The main ecological consequence of the Chernobyl disaster is the contamination of soil and agricultural products with biologically meaningful long-living radionuclide ^{137}Cs. Analysis of experimental data obtained from different traces after fallout of emissions from Chernobyl NPP showed that the dynamics of radionuclide transfer from soil to plants significantly depends on the physical and chemical

properties of the soil, properties of radionuclides as radioisotopes of specific chemical elements and correlations of different fallout components on different emission tracks (Prister et al., 1992; Ivanov et al., 1997). Soils of agricultural landscapes are one of the main objects where radionuclides ^{137}Cs are concentrated. They intensively transfer from the soil into biogenic migration along trophic chains and accumulate in plant and animal products and subsequently enter the human body (Strand et al., 1996; Michel et al., 2015).

The population living in areas which suffered from the Chornobyl disaster additionally receives extra doses of external and internal exposure above natural levels. Additional external radiation is caused by the high content of ^{137}Cs in the soil, the decay of which increases the amount of gamma radiation in this territory and internal radiation is caused by ^{137}Cs radionuclides entering the body when plant products obtained in contaminated areas are consumed (Prister et al., 1992; Jacob et al., 2009). In fact, plant products obtained from private plots are the main source of nutrition and intake of radionuclide ^{137}Cs for the rural population.

To assess the contribution of plant products grown on private land plots to the radiation dose, the specific activity of ^{137}Cs and the coefficients of its transition to plant products of Narodychi, Korosten and Ovruch districts of Zhytomyr region were calculated.

It is known that according to the Resolution of the Cabinet of Ministers of the Ukrainian SSR. On the organization of implementing resolutions of the Verkhovna Rada of the Ukrainian SSR on the order of introduction of the Law of Ukrainian SSR "On the legal regime of the area contaminated by the Chernobyl disaster" and "On status and social protection of citizens affected by the Chernobyl disaster" of 23 July 1991 number 106, residential places of Narodychi district: the small town Narodychi, the villages Rozsokhivske, Selets, Loznytsia and Hrystynivka were assigned to the zone of unconditional (mandatory) evacuation, and the village Radcha to the zone of guaranteed voluntary resettlement. Residential places of Korosten district, the village Obykhody were assigned to the zone of unconditional (mandatory) resettlement (zone 2), the town Korosten, the villages Bekhy, Grozyne, Voroneve and Berestovets to the zone of voluntary guaranteed resettlement (zone 3). Residential places of Ovruch district: the villages Rudnia and Vystupovychi to the zone of unconditional (mandatory) resettlement (zone 2), the town Ovruch, the villages Slovechne, Mozhari, Lystvyn and Novi Velidnyky to the zone of voluntary guaranteed resettlement (zone 3). According to the data of the radiological survey conducted in 2008, in the six northern districts of Zhytomyr region, 259.5 thousand hectares of agricultural land out of 377.3 thousand hectares, which constitutes 68.8%, are contaminated with ^{137}Cs, the contamination being distributed as follows: Korosten – 88.7, Lugyny – 48.7, Malyn – 88.7, Narodychi – 88.7, Ovruch – 44.3, Olevsk – 73.9% (Fig. 1). The majority of the districts of Zhytomyr region, except the six abovementioned and three districts (Novograd-Volynskyi, Volodarsko-Volynskyi and Yemilchyno) where the density of contamination of the territory to 37 kBq/km^2 amounts to 91.7–99.5%, belong to the category of districts with a density of pollution of agricultural land with ^{137}Cs to 1 Cu/km^2; the rest of the land has a radioactivity ranging from 37 to 185 kBq/m^2 (0.5–8.3% of the contaminated agricultural land).

The territory of the northern districts of the region was scaled according to ^{137}Cs as follows: from 1 to 5 Cu/km^2: Korosten – 44.7%, Lugyny – 90.2%, Malyn – 19.8%, Ovruch – 84.6%, Naryodychi – 81.2%, Olevsk – 61.9% of the total area of the contaminated territory. The percentage of the territory with a pollution density from 5 to 15 Cu/km^2 is as follows: Korosten – 2.9%, Lugyny – 2.4%, Malyn – 0.2%, Ovruch – 1.0%, Narodychi – 13.1%, Olevsk – 13.3% (Romanchuck, 2015). On such territories products "free" from radiation cannot be obtained. This is despite the fact that 30 years have passed since the Chernobyl disaster (Maringer et al., 2017).

Investigation of the ^{137}Cs content in the external environment showed that it amounts to 90% in the upper 20–30 cm layer. According to Michel et al. (2005), due to the penetration of radionuclides into the lower layers of the soil, inaccessible to the root system, as well as fixation with soil particles on average 0.7% of ^{137}Cs is lost per year.

The content of ^{137}Cs in the diet of the inhabitants of any area depends on the degree of pollution of the components of local food products, as well as on the ratio of imported and local products in the diet, the structure of the diet itself. In the US, the main source of ^{137}Cs is milk and meat (up to 60–70% of its total consumption), in Belarusian and Ukrainian Polissia these are milk (over 70% of daily intake) and potatoes (10–27%), but not bakery products as in other regions. This can be explained by the fact that bakery products are brought here from clean areas, and so local factors do not affect the concentration of ^{137}Cs in them (Matson et al., 2000, Maringer et al., 2017).

The natural processes of radionuclide decay in the 30 years since the disaster at the Chernobyl NPP have caused significant adjustments to the structure of radionuclide distribution in Ukraine. During this period the area of the territory where the contamination levels of ^{137}Cs exceeded 10 kBq/m^2 decreased by almost two times (Fig. 1).

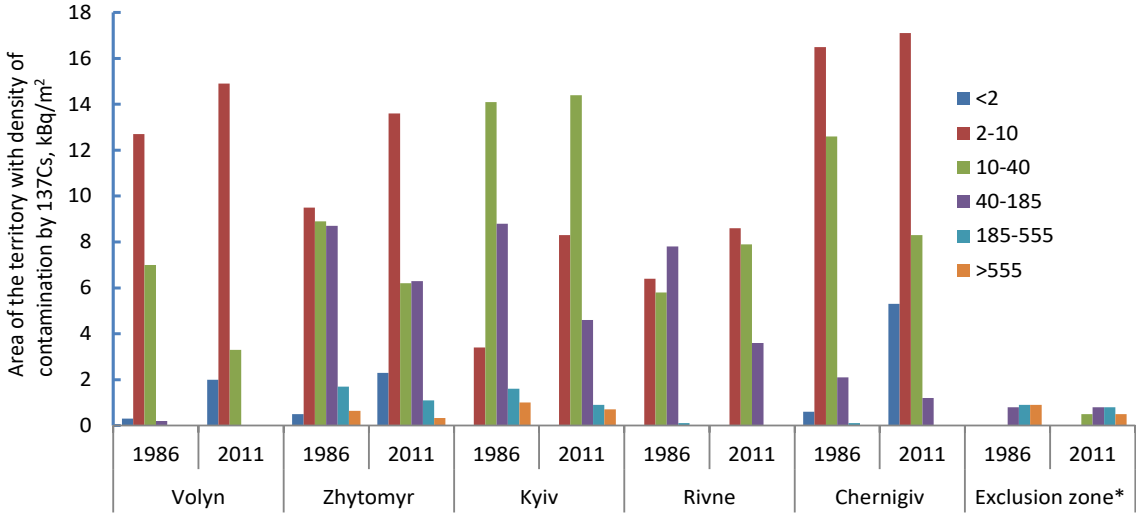

Fig. 1. Area of contamination with ^{137}Cs on the territory of Ukrainian Polissia in 1986 and 2011 (Romanchuck, 2015):
* – the area of the territory of the exclusion zone and the zone of unconditional mandatory resettlement, which is located on the territory of Kyiv region: in the tables in the first line the area of pollution was as of May 10, 1986, and in the second as of April 26, 2011

Studies on the distribution of radionuclides in the soil profile of all types of soils found that the main amount of radiocaesium in the long-term period after the disaster at the Chernobyl NPP is still concentrated in the arable soil layer (Michel et al., 2015). That is, the

main part of radionuclides is located in the root layer, and therefore, in the near future, one should not hope for their rapid movement into deeper horizons, and, consequently, for reduction of their penetration into plant products, and then intoanimals and human organisms.

The main region of contamination by radionuclides from the disaster at the Chernobyl NPP is located in Polissia region, which has granulometrically light soddy podzolic soils with low humus content, exchange bases and acidic pH. These conditions favour more intensive migration of ^{137}Cs into the "soil-plant" chain, which leads to its higher accumulation in plant and livestock products (Prister et al., 1992).

Many studies and observations have shown that the intensity of vertical migration is determined by the mechanical, physical and chemical properties of the soil, as well as the chemical nature of radionuclides (Ivanov et al., 1997). At the same time, the migration of radioactive substances along the profile of the soil may be the consequence both of the mechanical transfer of the particles from precipitation or soil particles with sorbent radionuclides, and the movement of free ions or their complexes with organic matter as a result of diffusion, convective transport with streams of water, formation of volatile compounds (Romanchuck et al., 2017).

As many studies show, 85–90% of radionuclide fallouts are accumulated in the upper layer of natural land or an arable layer of land, from where they are actively involved in trophic chains through root plant systems. Thus, in spite of sorption processes, redistribution of radionuclides on the soil profile, they remain within the zone of enhanced plant assimilation (Romanchuck et al., 2017).

The accumulation of radionuclides by various species and varieties of agricultural crops is determined by the peculiarity of mineral nutriation, the duration of the vegetative period, the nature of the distribution of root systems in the soil, different productivity and other biological characteristics. Leguminous cultures, as a rule, absorb most radionuclides more intensively than cereals (Prister et al., 1992).

Grain crops, tubers, root and vegetable crops have very low values of the transition coefficient of radionuclides from the soil. In addition, these cultures are traditionally grown on more fertile soil types, and more often using fertilizers. Therefore, in the long-term period after the disaster, radiocaesium content in these plant products did not exceed DR-2006 in almost all of the territory. However, when the local inhabitants grow vegetables, mainly potatoes, on black earth and soddy podzolic sandy and sandy loam soils, the specific activity of ^{137}Cs in products can reach the level of DR-2006, and sometimes exceed it. An example is the excess over the permitted content of ^{137}Cs in vegetables and potatoes grown on peat soils in recent years. The density of soil contamination with ^{137}Cs about 100 kBq/m^2 has a specific activity of radiocaesium in vegetables and potatoes that exceeds DR-2006 (Matson et al., 2000; Maringer et al., 2017).

An important factor that greatly changes the radiation situation in contaminated areas is the immobilization of radionuclides by the soil-harvesting complex. Moreover, the periods of half-decrease of the coefficients of radionuclide accumulation by plants owing to this process for ^{137}Cs are much smaller than periods of half-life of radionuclides, indicating more than decay, the contribution of immobilization processes to improving the radiation situation (Prister et al., 1992; Handl et al., 2003).

In recent years, due to the difficult economic situation in the country, there are cases of excess over DR-2006 content of radionuclides in agricultural products produced in the public sector in radioactive contaminated regions. This caused the necessity of carrying out a total monitoring of the quality of food consumed by the population in the northern districts of Zhytomyr region.

To assess the accumulation of ^{137}Cs in plant products, the activity of these radionuclides in potatoes, vegetable crops, root crops and grains was investigated, and coefficients of its transition from the soil to the products were calculated, which made it possible to estimate the intensity and volume of radionuclide accumulation at the completion of the half-life period of ^{137}Cs and the actual assessment of the radiation situation in the northern regions of Polissia.

Materials and methods

In the long-term period after the accident, the situation in the contaminated territories has improved and became predictable due to the natural processes of regeneration (physical decay of radionuclides, their redistribution and fixation in the soil profile) and implemention of countermeasures on the basis of monitoring. However, until today regions of Ukrainian Polissia produce agricultural products which do not meet the requirements of government regulations concerning the content of radionuclides in food and appear to be a danger to consumers exposure. The object of the research was the processes of migration of ^{137}Cs in the trophic chains, which lead to contamination of agricultural products and exposure of the population in the long-term period after the accident.

Materials of the research were samples of soil and plant products, selected on the plots of the residents of contaminated areas. Experimental studies on determining the radiation evaluation of soils and plant products were conducted in personal subsidiary farms of the residents of Zhytomyr Polissia (Table).

Table
Scheme of selecting samples
of agricultural products in residential places

Districts	Density of contamination, kBq/m^2	
	>555, zone 2	185–555, zone 3
Narodychi	small town Narodychi, villages Khrystynivka, Loznytsia, Selets, Rozsokhivske	village Radcha
Korosten	village Obykhody	town Korosten, villages Berestovets, Nemyrivka, Grozyne, Voroneve, Bekhy
Ovruch	villages Rudnia and Vystupovychi	Villages Mozhari, Novi Velidnyky, Slovechne, Lystvyn

The subject of the research is the concentration of ^{137}Cs in food products of vegetable origin in territories with different densities of radioactive contamination. The selection of soil samples for determining ^{137}Cs was conducted in accordance with state standard of Ukraine 4287:2004 "Soil quality. Sampling" and in accordance with "Methods of integrated radiation inspection of territories contaminated as a result of the Chernobyl disaster (except for the territory of the exclusion zone)". Before sampling, the gamma radiation dose (gamma background) in the air (expositional, absorbed or equivalent dose) was measured at the study site.

For this purpose, a checkered dosimeter DRG-01 T was used. Gamma shooting was conducted at a height of 1 m from the soil surface at five points. Measurements were made at least three times in each of the five points. The results of measurements were recorded in the logbook. Based on the obtained results, the average gamma dose rate was calculated. In the case when the maximum deviations did not differ from the average value by more than 30%, the site was considered to be homogeneously contaminated. When the maximum deviations differed from the average gamma dose rate by more than 30%, the plot was considered to be contaminated heterogeneously.

During the conducting of radiological control in a rural settlement, all its territory was taken as the surveyed area. In the natural landscape outside the settlement, an area of about 5 hectares was taken as the surveyed area.

Spot samples were taken with a sampler (a coring tube). To form a combined soil sample, 5 point samples were used. All sampling was carried out in 4 replications.

Preparation of soil samples for spectrometric studies was performed directly under laboratory conditions. The soil samples were dried at room temperature to air-dry state and ground on a grinding machine. After that, the soil was poured into Marinelli vessels, weighed on scales and a sample for measurements was placed into the device. The selection of plant products for determining ^{137}Cs was carried out in accordance with the guidelines "Sampling, initial processing and determination of ^{90}Sr and ^{137}Cs content in food products". In accordance with the requirements of the Law of Ukraine "On protection of

human rights against the effect of ionizing radiation" (15/98-BP), the content of radionuclides in food products, raw food materials and drinking water should not exceed the approved levels in the established order. Spot samples of plant products (corn cobs, green mass, tomatoes, beans, etc.) were collected from random plots of inhabitants by random sampling in 5–10 places. The mass of the average sample was not less than 1 kg.

Determination of ^{137}Cs in the soil and agricultural products was carried out in the Laboratory of Ecological Safety of Land, Environment and Quality of Products, at the Zhytomyr branch of the state institution "Institute for Soil Protection of Ukraine" with the help of the spectrometric method on a universal spectrometric complex "Gamma Plus" using a scintillation gamma spectrometer. The relative error of specific activity of radionuclides was 10–25%. Identifying specific activity of ^{137}Cs in plants and soil samples over the duration of investigations was carried out by the same methods and the same device, thus ensuring comparability of results throughout the entire period of the experiment.

Minimum specific activity when measuring in the geometry of a Marinelli vessel in standard protection for 1 hour with an error of measurement amounting to 25% was 3 Bq/kg. The energy range of γ-radiation is 0.05–3.00 MeV. As a parameter characterizing the migration of radionuclides in the soil-plant system, we used a transition coefficient (CT) equal to the ratio of the specific activity of the radionuclide in samples taken from plant products (Bq/kg) to the density of soil contamination (kBq/m^2).

The statistical processing of the material was carried out using the Statistica 7.0 (StatSoft Inc., USA) software packages. The methods of checking for the normality of the data distribution and the corresponding methods of correlation analysis were used. The graphs show the average data and the mean square deviation (SD).

Results

Density of soil contamination with ^{137}Cs in northern districts of Zhytomyr region. The density of soil contamination with ^{137}Cs and its specific activity in plant products grown on private plots were studied in three districts of Zhytomyr region: Narodychi, Korosten and Ovruch. Investigation of density of soil contamination with ^{137}Cs in Narodychi district, where five out of six investigated settlements belong to the zone of unconditional (obligatory) resettlement (small town Narodychi, villages Rozsokhivske, Selets, Loznytsia, Khrystynivka) and only one to the zone of guaranteed voluntary resettlement (Rudnia village), showed that the content of this radionuclide in these places is within the limits of 555 kBq/m^2 (Fig. 2).

The highest value of density of soil contamination was recorded in zone II within the villages Loznytsia – 417.2 kBq/m^2 and Khrystynivka – 401.8 kBq/m^2. The lowest indicator was noted in the village Rozscokhivske – 158.8 kBq/m^2. From the data of the figure it can be seen that the density of soil contamination on the plots of land in the village Radcha, which belongs to the third zone of radioactive contamination, amounted to 169.8 kBq/m^2, which in comparison with the adjoining areas of the second zone of the Narodychi district: small town Narodychi, villages Selets, Loznytsia and Khrystynivka, is respectively less – by 30.7%, 69.7%, 245.7% and 236.6%. It is worth noting that in the area adjacent to the village Rozskochivske (zone II) the density of soil pollution was less than in the village Radcha by 11 kBq/m^2 or 6.5%.

Consequently, the average density of contamination of plots in inhabited sites with ^{137}Cs was 271.5 kBq/m^2. This indicates that according to the level of soil contamination with ^{137}Cs and the Law of Ukraine "On the legal regime of the territory that was exposed to radioactive contamination as a result of the Chernobyl disaster", the territories under human settlement should still be allocated to the zone of unconditional (mandatory) resettlement. A similar situation also occurred in residential sites in Ovruch district. There 2 residential sites which are a part of the zone of unconditional (compulsory) resettlement (village Rudnia and village Vystupovychi) and 5 settlements of the guaranteed voluntary resettlement zone (town Ovruch, villages Slovechne, Mozhari, Lystvyn and Novi Velidnyky) were selected for investigation (Fig. 3).

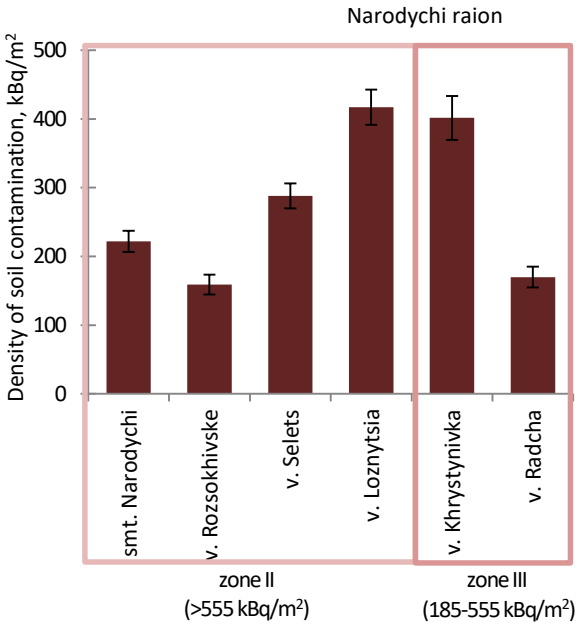

Fig. 2. Density of soil contamination with ^{137}Cs in six settlements of Narodychi district: vertical columns – average values, vertical bars – standard deviation, n = 20 for each group

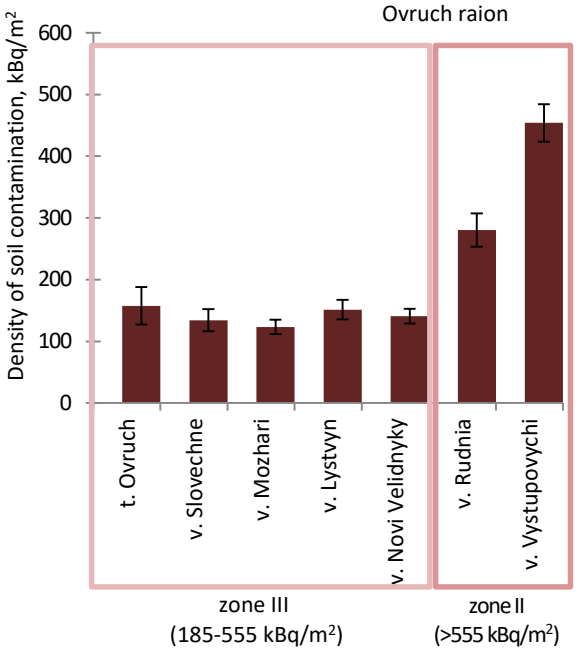

Fig. 3. Density of soil contamination with ^{137}Cs in settlements in Ovruch district: see Fig. 2

Investigation of activity of radionuclides of ^{137}Cs on the household plots of inhabitants of Ovruch district (II zone) showed that levels of contamination of plots of land were high. The highest value of density of soil contamination was recorded in zone II in the village Vystupovychi, where this indicator reached 454.0 kBq/m^2, which is 173.5 kBq/m^2, or 61.8% more than in the village Rudnia. In another populated area of zone II, Rudnia village indexes of soil pollution with ^{137}Cs were much lower – 280.5 kBq/m^2. Within zone III, the density of soil contamination with ^{137}Cs was 2–3 times lower compared with zone II. There, the density of soil contamination in all settlements was approximately on the same level and varied from

123.3 to 157.6 kBq/m^2. The level of contamination with ^{137}Cs of soils of private household plots in Ovruch district (III zone) was from 123.3, in Mozhari village and it amounted to 157.6 kBq/m^2, in Ovruch town. On average, the density of contamination with ^{137}Cs of plots in residential sites was 141.4 kBq/m^2. This indicates that according to the level of soil contamination with ^{137}Cs and the Law of Ukraine "On the legal regime of the territory that was exposed to radioactive contamination as a result of the Chernobyl disaster", the territory of human settlements still currently belongs to the zone of guaranteed (voluntary) resettlement.

In general, in Ovruch district, the density of soil contamination with ^{137}Cs was on average 367.3 kBq/m^2. This indicates that according to the level of soil contamination with ^{137}Cs and the Law of Ukraine "On the legal regime of the territory that was exposed to radioactive contamination as a result of the Chernobyl disaster", the territory of human settlements still currently belongs to the zone of unconditional (mandatory) resettlement; this is the territory that was subjected to intense pollution with long-lived radionuclides, with a density of soil contamination with isotherm caesium above the pre-accident level, which is from 15.0 Cu/km^2 and above, where the estimated effective equivalent dose of human radiation taking into account radionuclide migration in plants and other factors may exceed 5,0 mSv (0.5 rem) per year above the dose it received in the pre accident period.

There is another situation in the Korosten district. Seven residential sites were selected for research there, six of which belong to the zone of guaranteed voluntary resettlement (the town Korosten, the villages Grozyne, Voroneve, Berestovets, Bekhy and Nemyrivka) and one to the zone of unconditional (compulsory) resettlement (Obykhody village).

Studies on the activity of radionuclides in the soils of Korosten distrct (zone 3) showed that soil contamination of plots with ^{137}Cs was high and ranged from 153.8 in the village Berestovets to 239.7 kBq/m^2 in the village Bekhy, on average it was 193.6 kBq/m^2. The density of soil pollution in the residential sites can be divided into 2 groups: 1 – density of contamination up to 200 kBq/m^2 (the village Berestovets – 153.8, Grozyno – 170.2, Korosten town – 186.6 kBq/m^2), which was respectively 20.5%, 12.1% and 3.6% lower than the average in settlements, and group 2 – the contamination density was more than 200 kBq/m^2 (the villages Nemyrivka – 203.4, Voroneve – 207.7, Bekhy – 239.7 kBq/m^2), which is respectively 5.1%, 7.3% and 23.8% more than the average (Fig. 4).

In general, it should be noted that the most polluted were the settlements of Naryodychi and Ovruch districts, which belong to the zone of unconditional (mandatory) resettlement: the villages Vystupovychi, Loznytsia and Khrystynivka, where the density of pollution ranged from 454.0–401.8 kBq/m^2. Within the zone of guaranteed voluntary resettlement, the most polluted soils were in Korosten district, where the density of pollution sometimes reached 239.7 kBq/m^2 (village Bekhy).

Analysis of the density of soil pollution by ^{137}Cs isotopes in the northern part of Zhytomyr region in the post-accident period shows that even 30 years after the tragedy, large areas of arable land under certain conditions are potentially dangerous because of contamination of plant products.

Specific activity of ^{137}Cs in plant products grown on the plots of the inhabitants of the northern districts of Zhytomyr region

We studied the specific activity of ^{137}Cs in plant products grown on the plots of the inhabitants in the same residential sites where soil contamination was observed. We have compiled a list of food products that form the basis of the diets of residents of the northern districts of Zhytomyr region. In particular, the list of crops that were investigated included: potato tubers, white cabbage, fresh tomatoes, table beets, carrots, onions, beans, oat grains, corn grains.

The results of the research showed that the specific activity of ^{137}Cs in all plant products was lower than the permitted levels in Narodychi district within the settlements of zone III (village Radcha) (Fig. 5).

A slightly different situation occurred in human settlements places that belong to the second zone. In general, the specific activity of ^{137}Cs in plant products there dynamically varied from the minimum value of 4.1 (fresh tomatoes, village Rozskhivske) to the maximum – 82.4 Bq/kg (beans, village Loznytsia), depending on the type of plants. In particular, exceedance of the permissible level of specific activity of ^{137}Cs was observed in table beets in the settlements Loznytsia and Khrystynivka – 51.3 and 48.6 Bq/kg respectively, and table carrots in the settlement Loznytsia – 45 Bq/kg, in village Khrystynivka the content of ^{137}Cs in carrots practically approached the limit of the permissible level of 38.7 Bq/kg, while DR is 40 Bq/kg.

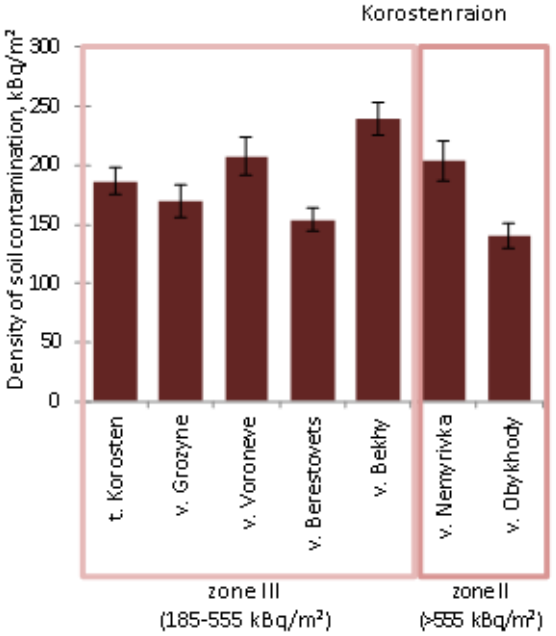

Fig. 4. Density of soil contamination with ^{137}Cs in settlements in Korosten district: see Fig. 2

It was discovered that the most critical product, where the highest specific activity of ^{137}Cs was recorded, was beans. Excess of the maximum permissible level of specific activity of ^{137}Cs in beans was fixed in 4 settlements: in village Loznytsia – 82.6 Bq/kg, which is 1.64 DR, village Khrystynivka – 77.4 Bq/kg, which is 1,54 DR, village Selets – 61.1 Bq/kg, which is 1.22 DR and the small town Narodychi – 54.2 Bq/kg, which is 1.1 DR – 2006.

In all other products, the specific activity of ^{137}Cs was low. In particular, the lowest values were recorded for onions, where, even in the most polluted settlements (villages Loznytsia and Khrystynivka), they varied within the range of 14.6–15.2 Bq/kg, while in other settlements of the Narodychi district they did not even exceed the limits of 10 Bq/kg (5.0–9.8 Bq/kg).

A similar situation was noted for fresh tomatoes and white cabbage. For tomatoes, the highest index of specific activity was recorded in the village Loznytsia – 17 Bq/kg and the village Khrystynivka – 15.8 Bq/kg, which is slightly less than half of DR-2006 (40 Bq/kg). For cabbage it was noted in the village Khrystynivka – 21.1 Bq/kg and the village Loznytsia – 20 Bq/kg. In other residential places, the specific activity of ^{137}Cs in tomatoes and cabbage was even lower and ranged from 4.1 to 12.7 Bq/kg and from 6.0 to 15.4 Bq/kg, respectively.

As is well known, a significant proportion of the diet of residents of the northern raions of Zhytomyr region is potatoes. Therefore, the data on the specific activity of ^{137}Cs in this product was of considerable interest. As a result of the research, no excess of DR-2006 was recorded in any of the settlements. The maximum recorded value of specific activity of ^{137}Cs was noted in the village Khrystynivka – 35.4 Bq/kg and in the village Loznytsia – 33.6 Bq/kg. In other settlements of the Narodychi district, the specific activity of ^{137}Cs in potato tubers was even lower and was noted at the level of 10.5–21.3 Bq/kg, which is about 1/3–1/6 of DR-2006 (60 Bq/kg). A slight specific activity of ^{137}Cs was observed in grain crops. In particular, oat grains and corn grains were checked. Specific activity in

the grains of both crops was approximately the same. The highest values recorded were recorded in the village Loznytsia – 28 Bq/kg in corn grains and the village Khrystynivka – 26.7 Bq/kg in oat grains and 27.3 Bq/kg in corn grains. Even lower rates were recorded in other settlements, where the specific activity of ^{137}Cs in oat grains varied from 11 to 20.2 Bq/kg and corn grains – from 11.5 to 21.6 Bq/kg, which is significantly lower than DR-2006 (50 Bq/kg). The coefficients of transition of ^{137}Cs in the settlements of zone 3 of Narodychi district (village Radcha) into plant products varied from 0.05 (fresh tomatoes) to 0.18 (beans). Depending on the type of plants, the highest CT values were characteristic for beans – 0.18 and table beets – 0.11. The lowest CT values were for onions and fresh tomatoes – 0.05. The situation was considerably better in the Korosten district, where, despite the rather high indicators of density of soil contamination with ^{137}Cs, plant products collected from the private plots of the inhabitants were "clean" (Fig. 6).

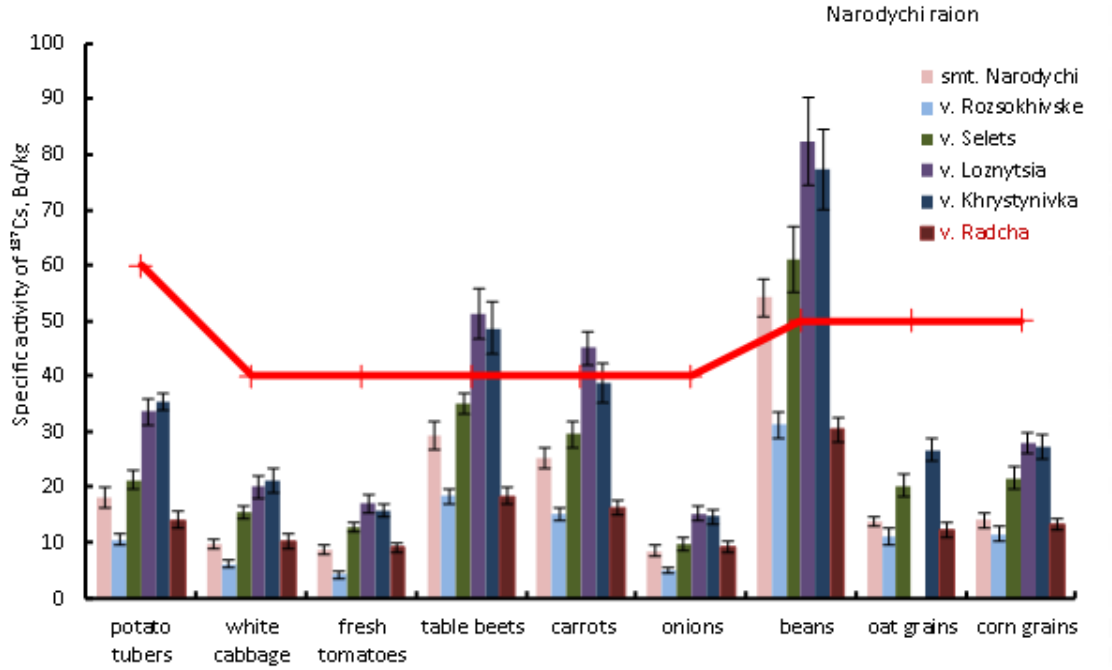

Fig. 5. Specific activity of ^{137}Cs in plant products grown on private plots of citizens in Narodychi district: the red line indicates the maximum permitted levels of ^{137}Cs radionuclide content in foodstuffs in accordance with the State Hygiene Standards of the Ministry of Health of Ukraine (dopustymi rivni vmistu radionuklidiv ^{137}Cs ta ^{90}Sr u kharchovykh produktakh ta pytniy vodi, DR-2006 [Acceptable levels of radionuclide ^{137}Cs and ^{90}Sr in food and drinking water, DR-2006]), in the legend, in red are identified the areas belonging to the zone III of radioactive contamination (guaranteed voluntary resettlement), the black zone – to zone II of radioactive contamination (unconditional (obligatory) resettlement); vertical columns – average values, vertical bars – standard deviation, n = 10 for each group

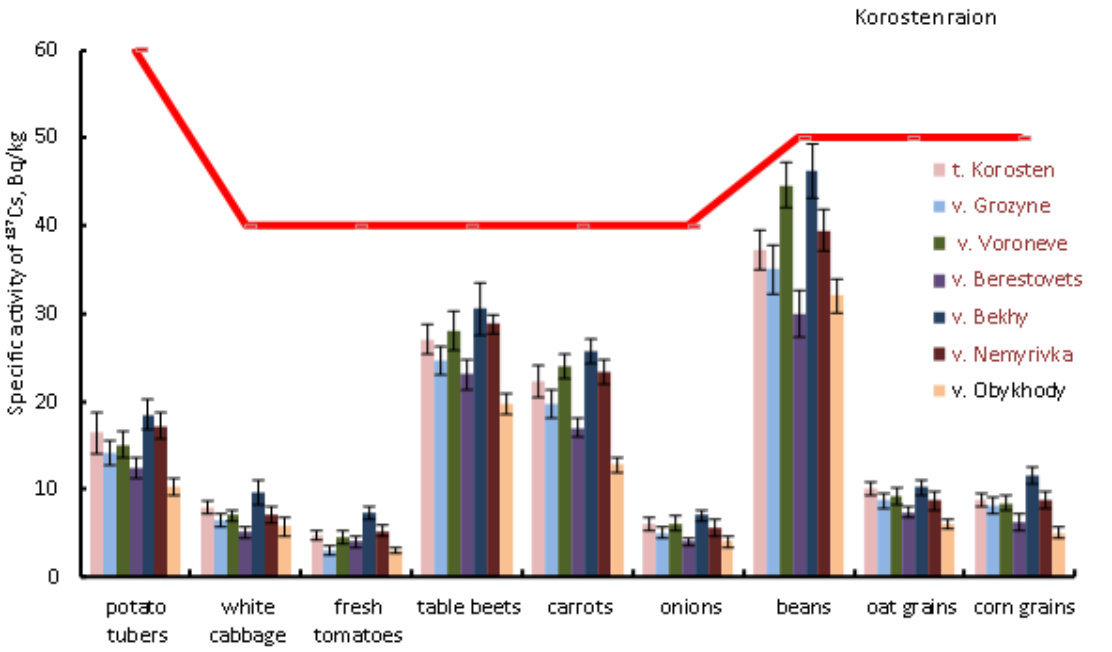

Fig. 6. Specific activity of ^{137}Cs in plant products grown on private plots of inhabitants of Korosten district: see Fig. 5

As in Narodychi district, the most critical products were beans, table beets and carrots. The highest values of specific activity of beans were recorded in village Bekhy – 46.3 Bq/kg and village Voroneve – 44.6 Bq/kg at DR-2006 – 50 Bq/kg, where previously the highest density of soil pollution with ^{137}Cs was noticed. In other settlements, the specific activity of ^{137}Cs in beans was roughly the same and in

zones II and III, there it varied within 30.0–39.4 Bq/kg. In table beet, the specific activity of ^{137}Cs did not exceed the DR-2006 in general, and it was the highest in village Bekhy – 30.5 Bq/kg, village Nemyrivka – 28.8 Bq/kg and village Voroneve – 28.1 Bq/kg, in other residential places the specific activity of ^{137}Cs in beets was even lower and ranged from 19.7 to 27 Bq/kg. A similar trend was noted for carrots, the maximum indicators of specific activity were recorded in the same settlements as for table beets. In general, the specific activity of ^{137}Cs for carrots in the district was recorded in the range from 12.8 to 25.7 Bq/kg, which is 1/3–1/2 ofthe established DR.

As in the previous district, the "cleanest" were onions and tomatoes. In these products, the specific activity of ^{137}Cs was 6–10 times lower than the established DR. For onions there was no significant fluctuation of values between the settlements, and in general, the indicators fluctuated within 4.0–7.0 Bq/kg, for tomatoes – 3.0–7.3 Bq/kg.

A similar trend was observed for white cabbage, in particular, the specific activity of ^{137}Cs in this product was 4–8 times lower than the established DR. Significant fluctuations of indicators in the context of settlements were also not noted and in general, the specific activity of ^{137}Cs in cabbage ranged from 5.1 to 9.7 Bq/kg. The specific activity of ^{137}Cs in potatoes was also not significant. In general, this value varied from 10.3 to 18.5 Bq/kg in the settlements of Korosten district, which did not exceed a third of the established DR-2006.

A slight specific activity of ^{137}Cs was observed in grain crops. Specific activity of ^{137}Cs in the grain of both crops was approximately the same. The highest rates were recorded in village Bekhy – 11.6 Bq/kg in corn and 10.2 Bq/kg in oats. Lower rates were noted in other settlements, where the specific activity of ^{137}Cs in oat grains varied from 6.0 to 10.1 Bq/kg and in corn grains from 5.0 to 11.6 Bq/kg, which is 5–10 times lower than DR-2006 (50 Bq/kg).

If we rank the crops according to the specific activity of ^{137}Cs, we obtain the following ranking: beans – 32, table beets – 19.7, carrots – 12.8, potato tubers – 10.3, white cabbage – 5.7, oat grains – 6.0, corn grains – 5.0, onions – 4.0 and fresh tomatoes – 3.0 Bq/kg.

One of the most critical was Ovruch district, in particular the village Vystupovychi, which belongs to zone II. In this settlement, a rather high level of soil pollution was noted – 454 kBq/m^2, this settlement proved to be the most critical out of all investigated settlements, and, accordingly, the highest values of the specific activity of ^{137}Cs were recorded in the products grown there (Fig. 7).

The activity of ^{137}Cs in general in the district varies widely enough – from 5.0 for onions (village Rudnia, density of soil contamination is 280.5 kBq/m^2) to table beets – 109.2 Bq/kg (village Vystupovychi, density of soil contamination 454.0 kBq/m^2).

As in the previous two districts, beans were the most critical product. Excess of DR-2006 for this type of product was recorded only in village Vystupovychi, where its specific activity reached 109 Bq/kg, which is 2 times more than the established DR-2006, in other settlements, the excess of DR was not recorded. Within zone III, the values of specific activity of ^{137}Cs in beans varied from 19.2 to 30.0 Bq/kg, while in village Rudnia which belongs to zone II as well as village Vystupovychi, the specific activity of ^{137}Cs in beans was 36.3 Bq/kg.

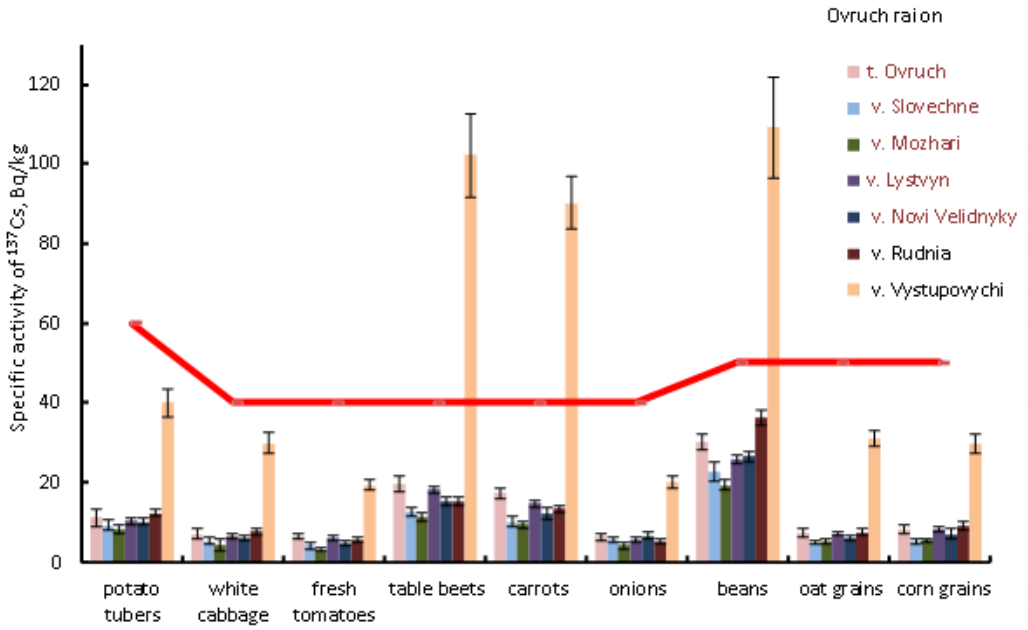

Fig. 7. Specific activity of ^{137}Cs in plant products grown on private plots of inhabitants of Ovruch district: see Fig. 5

Significant excess of DR-2006 in village Vystupovychi was also noted for table beets and carrots, the specific activity of ^{137}Cs in which was noted at 102.2 and 90.2 Bq/kg, which is 2.5 DR and 2.2 DR, respectively. In other residential places of the Ovruch district, excess of DR-2006 in products of table beets and carrots was not observed, and the values of specific activity were recorded at 11.2–19.4 Bq/kg for table beets and 9.4–17.2 Bq/kg for carrots.

Potato tubers accumulated ^{137}Cs slightly, that is, the trend noted in the Narodychi and Korosten districts was observed here as well. Exceedance of DR-2006 was not observed. In general, this value in the context of settlements of the Ovruch district ranged from 8.1 to 12.3 Bq/kg, which did not exceed one fifth of the established DR-2006. However, the highest index of specific activity of ^{137}Cs in potatoes, similar to other agricultural crops, was recorded in village Vystupovychi – 40 Bq/kg. Such cultures as white cabbage, tomatoes and onions were not polluted in this area. The highest indicators of specific activity for these products were recorded in village Vystupovychi – 29.7 Bq/kg for white cabbage, 20.1 Bq/kg for onions and up to 19.3 Bq/kg for tomatoes. In other settlements there were no significant variations in the indicators. For white cabbage the value varied from 4.3 to 7.5 Bq/kg, which is 5–9 times less than the DR-2006. For tomatoes, the variation of the indicators was within the range of 3.0–6.3 Bq/kg, which is 6–13 times less than the DR-2006. For onions – 4.0–6.6 Bq/kg, which is 6–10 times less than the DR-2006.

Insignificant specific activity of ^{137}Cs was noted in grain crops, as in other studied areas. Specific activity of ^{137}Cs in the grain of both crops was approximately the same. The highest rates were recorded in village Vystupovychi – 29.6 Bq/kg in corn and 30.8 Bq/kg in oats. Lower indexes were noted in other settlements, where the specific activity of ^{137}Cs in oat grains varied from 4.8 to 7.4 Bq/kg and in corn grains – from 5 to 9 Bq/kg, which is 5–10 times lower than DR-2006 (50 Bq/kg). Average specific activity of ^{137}Cs in the private plots in village Vystupovychi was 58.9 Bq/kg, and in village Rudnia it was 13.9 Bq/kg, which is by 45.0 Bq/kg, or by 76.4% lower.

The activity of ^{137}Cs in fresh tomatoes was 5.6 times lower than that of beans, for white cabbage – 3.7 times, for potatoes – 2.7, for carrots – 1.21 times lower than beans. It should be emphasized that the higher the density of soil contamination, the greater the SA of ^{137}Cs in plant products.

Consequently, according to the results of the research it is evident that the most critical settlements were located in the second zone – village Vystupovychi of Ovruch district and villages Loznytsia and Khrystynivka of Narodychi district. In these settlements, the excess of DR-2006 in plant products was observed, despite the fact that the excess of the maximum permissible level of density of soil pollution was not noted. Beans, table beets and carrots turned out to be the most critical in all areas of research.

Coefficients of transition of ^{137}Cs from the soil into plant products in the northern districts of Zhytomyr region

Analysis of literary sources has shown that the accumulation of ^{137}Cs in agricultural crops varies widely enough, depending on the content of humus, the reaction of the medium, the content of exchangeable forms of potassium, calcium in the soil, varietal features of plants. In previous investigations, we conducted monitoring research on agricultural land and in private farms of the most radioactively contaminated areas of Zhytomyr region.

The research covered various types of plant products, which significantly differed in the parameters of migration of Cs in the "soil – plant" system. Also, during the experiment, we determined the transition coefficients of ^{137}Cs in 9 types of agricultural crops. These cultures are known to form the basis of the diet of the population of radioactively contaminated territories, and due to the consumption of these products, a dose of internal radiation of the population is received.

The received transition coefficients characterize the current state of migration of ^{137}Cs from the soil to plant products in the private plots of inhabitants of residential places of Narodychi district. Investigating the activity of ^{137}Cs in plant products has shown that their content depends on the level of soil contamination by these radionuclides. The results of the research make it clear that the content of ^{137}Cs in plant products is directly proportional to the density of soil contamination by these radionuclides.

The results of the research in Narodychi district showed that the highest coefficients of transition of ^{137}Cs are characteristic for beans. During the study of all settlements in this area, the transition coefficients here approached the value of 0.2, and in the small town Narodychi and village Selets CT of ^{137}Cs in bean plants is even higher – 0.24 and 0.21, respectively. In other settlements, the transition coefficients were approximately the same – 0.18–0.20 (Fig. 8).

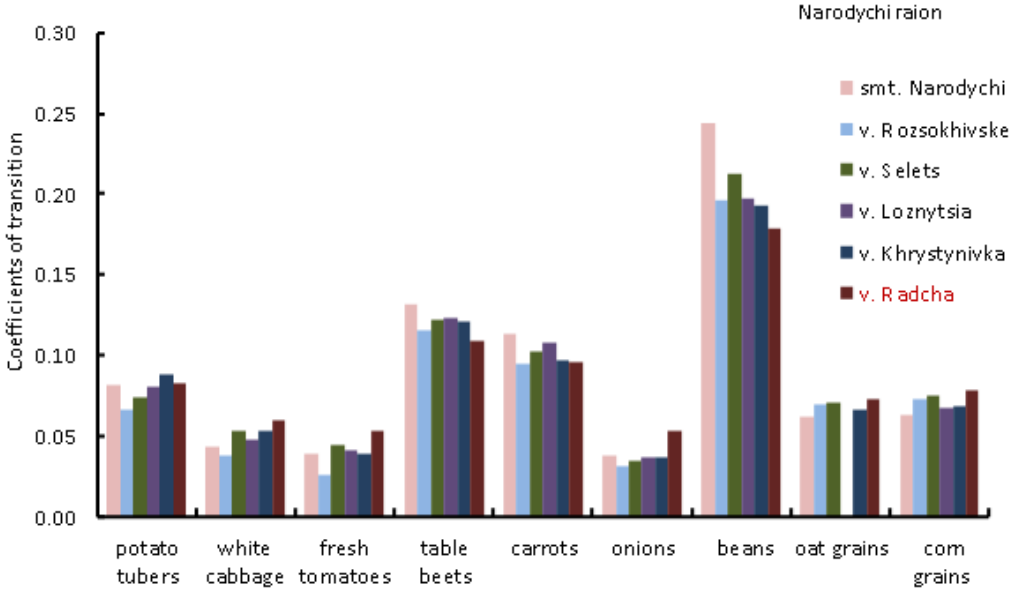

Fig. 8. Coefficients of transition of ^{137}Cs from the soil into plant products in Narodychi district: in the legend, in red are identified the areas belonging to the zone III of radioactive contamination (guaranteed voluntary resettlement), the black zone – to zone II of radioactive contamination (unconditional (obligatory) resettlement)

Somewhat lower coefficients of transition are characteristic of crops, table beets and carrots, in which excess of DR-2006 was recorded in the most polluted settlements – village Loznytsia and village Khrystynivka. For both of these cultures, the highest coefficients of transition of ^{137}Cs were also noted in the small town Narodychi – 0.13 for table beets and 0.11 for carrots. In other settlements, the coefficients of transition were recorded at almost one level – 0.12, except for the village Radcha, where this value was 0.11. For carrots, CT in the context of settlements varied in the range of 0.09–0.11.

Even lower coefficients of transition are characteristic for potato tubers. In particular, the highest CT was calculated for the village Khrystynivka – 0.09, in other settlements it was 0.07–0.08.

Approximately in the same quantities ^{137}Cs passes into the studied grain crops – oat and corn grains. For both of these crops, CT was calculated at 0.07, only in the small town Narodychi was CT lower – 0.06. We associate this fact with a variety of soil conditions in the area under research.

The lowest CT was recorded for white cabbage, onions and tomatoes. For white cabbage the maximum CT was calculated at the level of 0.06 in village Radcha, the minimum 0.04 – in the small town Narodychi and village Rozsokhivske. For onions and tomatoes, maximum CT was also calculated in village Radcha – 0.05 for both cultures, the minimum – 0.03 in village Rozsokhivske.

Thus, according to the results of research, it is clear that in order of decreasing value of CT of ^{137}Cs, the crops are ranked as follows: beans (0.24), table beets (0.12), carrots (0.11), potato tubers (0.08), corn grains (0.07), oat grains (0.06), white cabbage (0.05) and onions (0.04). From the data it is clear that ^{137}Cs in grain crops is mostly carried out from soil with vegetative weight of plants, namely corn grown for grain and has a CT of 0.07. Grain crops can also be arranged in a descending order: corn grain – oats grain.

Plant products grown on private plots in settlements of Korosten district (zone II) according to GN 6.6.1.1-130-2006 "Acceptable levels of ^{137}Cs in food and drinking water" meet the criteria for radiation safety. The coefficients of transition of ^{137}Cs to plant products differ from each other by 8.69 times.

Similarly to the data obtained in Narodychi district, the highest coefficients of transition of ^{137}Cs were characteristic of beans. The range of CT values was similar to that obtained in Narodychi district. Almost all the values of CT of ^{137}Cs in beans were close to

0.20 and in village Obykhody it was even higher – 0.23. In other settlements, the transition coefficients were approximately the same – 0.19–0.21 (Fig. 9).

Higher CT of ^{137}Cs for table beets and carrots were obtained in Korosten district in comparison with CT of ^{137}Cs for similar crops in Narodychi district. The highest CT of ^{137}Cs for table beets was calculated in village Berestovets – 0.15, in other settlements CT of ^{137}Cs was 0.13–0.14. The coefficients of transition of ^{137}Cs for carrots were at the same level for practically all settlements – 0.11–0.12, only in village Obykhody was the CT of ^{137}Cs lower – 0.09.

The highest CT of ^{137}Cs for potato tubers was recorded in the town Korosten – 0.09. The lower coefficients were calculated for other settlements 0.07–0.08, which again confirms the data obtained in Narodychi district. If compared to Narodychi district, received CT of ^{137}Cs for grain crops, oat and corn grains were lower. For both of these crops CT was calculated at the level of 0.04–0.05.

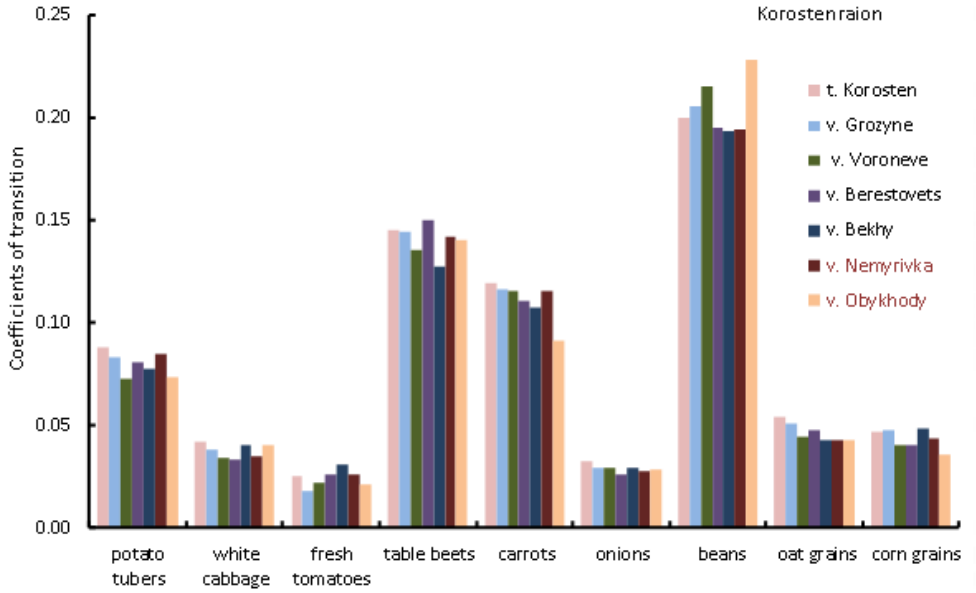

Fig. 9. Coefficients of transition of ^{137}Cs from the soil into plant products in Korosten district: see Fig. 9

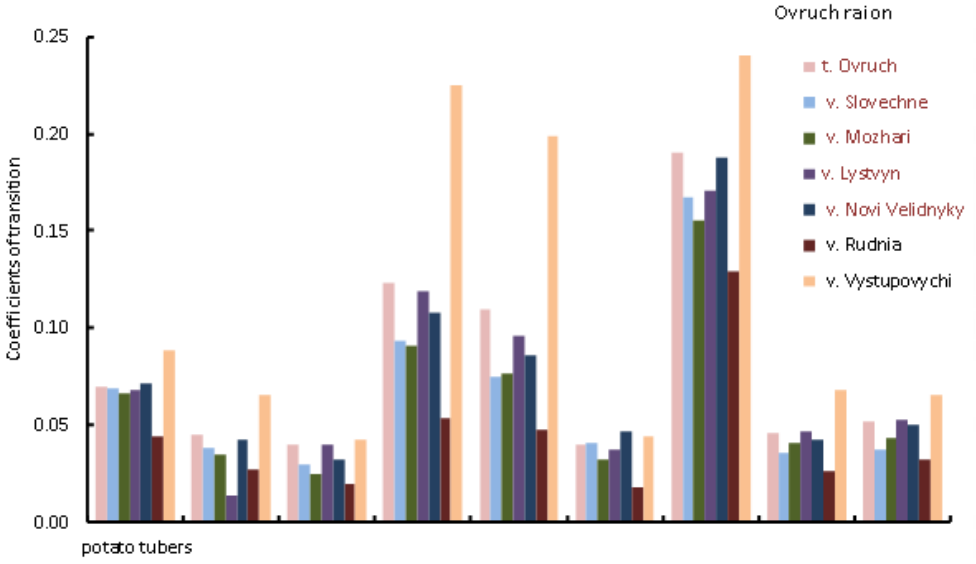

Fig. 10. Coefficients of transition of ^{137}Cs from the soil into plant products in Ovruch district: see Fig. 8

The lowest CT of ^{137}Cs was characteristic of white cabbage, onions and tomatoes. For white cabbage, CT of ^{137}Cs appeared to be lower than in Narodychi district and varied in the range of 0.03–0.04. For onions and tomatoes CT of ^{137}Cs for both cultures varied within the range of 0.02–0.03, which is also lower than in Narodychi distict.

According to the results of research in Ovruch district, the highest coefficients of transition of ^{137}Cs were observed for beans, similar to the data obtained in Narodychi and Korosten districts. However, CT of ^{137}Cs varied in a wider range of values than in the previous two districts. The highest CT of ^{137}Cs was recorded in village Vystupovychi, where the density of soil contamination with ^{137}Cs was the highest among all selected samples – 454 kBq/m^2. CT of ^{137}Cs in bean plants calculated for other settlements of Ovruch district varied from 0.16 to 0.19. Only in village Rudnia was CT of ^{137}Cs calculated at the level of 0.13 (Fig. 10).

The highest CT of ^{137}Cs in table beets and carrots was obtained from the calculations of data obtained in village Vystupovychi. Here they amounted to 0.23 for table beets and 0.20 for carrots. These CT values of ^{137}Cs were the highest among all of the studied districts. The lowest CT of ^{137}Cs was obtained in village Rudnia, there CT of ^{137}Cs for table beets and for carrots was 0.05. In other settlements of the district, the value of CT of ^{137}Cs varied for beets in the range from 0.09 to 0.12, and for carrots – from 0.7 to 0.12, which practically confirms the data obtained earlier in Narodychi and Korosten districts.

The highest CT of ^{137}Cs in potato tubers were also obtained in village Vystupovychi – 0.09, however, for this culture there was no

significant difference in coefficients in comparison with other settlements (CT of ^{137}Cs = 0.07), which completely corresponds to the data obtained in the other districts researched. The lowest CT of ^{137}Cs in potato tubers was obtained in village Rudnia, there it was 0.04.

Similar data for CT of ^{137}Cs in grain crops were obtained in all three districts researched. In particular, calculated CT of ^{137}Cs for oat and corn grains in Ovruch district varied within 0.04–0.05. The highest value was obtained in village Vystupovychi, where CT of ^{137}Cs was at the level of 0.07, the lowest in village Radcha – 0.03 for both cultures.

Similarly to data obtained in other districts, ^{137}Cs accumulated in white cabbage, tomatoes and onions. In particular, for white cabbage CT of ^{137}Cs was 0.03–0.04. The highest CT of ^{137}Cs was received in village Vystupovychi – 0.07. The lowest CT of ^{137}Cs was recorded in village Lystvyn – 0.01. We associate this difference with the difference in the soil conditions of these settlements. For tomatoes, obtained CT of ^{137}Cs repeated the data from other districts researched. Here, CT of ^{137}Cs varied slightly – 0.02–0.04. A similar trend is also characteristic for CT of ^{137}Cs in onions (0.02–0.05).

In general, the analysis of calculated CT of ^{137}Cs according to the data obtained in the three northern districts of Zhytomyr region showed that regarding the accumulation of ^{137}Cs, the most critical products were beans, table beets and carrots. The highest CT of ^{137}Cs was obtained in all three districts – village Obykhody in Korosten district, village Vystupovychi in Ovruch district and the small town Narodychi. The average CT of ^{137}Cs in beans was recorded at 0.20 (Fig. 11).

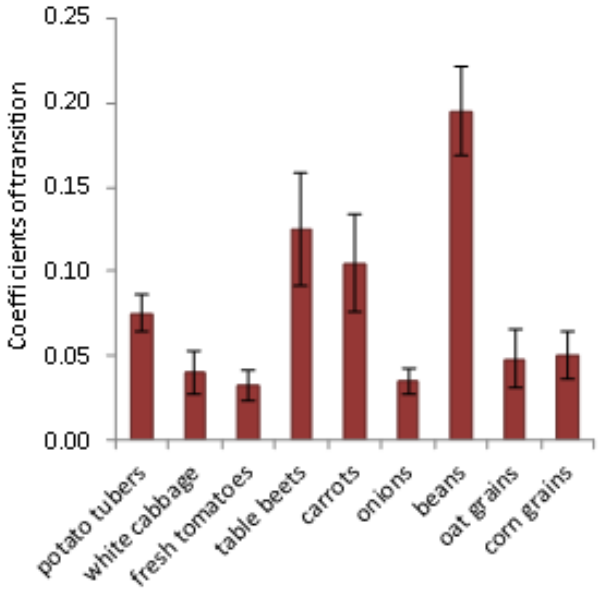

Fig. 11. Average coefficients of transition of ^{137}Cs from the soil into plant products in the northern districts of Zhytomyr region: vertical columns – average values, vertical bars – standard deviation, n = 20 for each group

For table beets, the average value of CT of ^{137}Cs was 0.13. However, the maximum value was 0.23 in village Vystupovychi of Narodychi district. The average value of CT of ^{137}Cs for carrots was calculated at the level of 0.11. Lower CT of ^{137}Cs was detected in the analysis of data on the accumulation of ^{137}Cs in potato tubers, where CT of ^{137}Cs was marked at 0.08.

Significantly lower average values of CT of ^{137}Cs were calculated for oat and corn grains – 0.05, white cabbage and onions – 0.04, and fresh tomatoes – 0.03. Thus, according to the results of the research, it is clear that in order of decreasing value of CT of ^{137}Cs, the crops are ranked as follows: beans > table beets > carrots > potato tubers > corn grains > oat grains > white cabbage > onions > fresh tomatoes. The results of the studies indicate that there is a direct proportional relationship between activity of ^{137}Cs in vegetable crops and the density of soil contamination.

According to GN 6.6.1.1-130-2006 "Permissible levels of radionuclide content of ^{137}Cs in food and drinking water", the activity of ^{137}Cs in potatoes should not exceed 60 Bq/kg, in fresh vegetables and legume crops – 40 Bq/kg. Therefore, vegetable products grown on private plots in Ovruch district do not all meet the criteria for radiation safety.

Discussion

The Chernobyl disaster led to the pollution of agricultural lands with a mixture of nuclear fission products, plutonium radionuclides and other transuranium elements. The radiation effects of the Chernobyl emissions are determined at present and for the long-term period by biologically significant radionuclides.

Over the period of the development of nuclear energy at enterprises of the nuclear fuel cycle, more than 450 radiation accidents with various consequences for the environment and different amounts of radionuclides that entered the biosphere have occurred. The disaster at the Chernobyl NPP was the largest of them. The most dangerous artificial radionuclides that contaminated the environment were ^{131}I, ^{137}Cs and ^{90}Sr. Among the paths of radionuclide entry into the human body, the main one is oral. Long after the accident, long-lived radionuclides ^{137}Cs and ^{90}Sr, which form the dose of internal radiation, were entering the human body through food products.

As has been previously mentioned, the main ecological consequence of the Chernobyl disaster is the pollution of soils and agricultural products with long-lived, biologically significant radionuclide ^{137}Cs. The analysis of our experimental data once again confirmed the results of a number of studies obtained in various traces of the fallout from the Chernobyl NPP; it showed that the dynamics of the transition of radionuclides from the soil to plants significantly depends on the physical and chemical properties of soils, the properties of radionuclides as isotopes of specific chemical elements and relations of different components of fallout in various traces of emission (Handl et al., 2003).

Outside the exclusion zone, the primary role in dosage formation, as in previous years (Prister et al., 1992; Handl et al., 2003; Hinton et al., 2007), belongs to ^{137}Cs. In most areas outside the 30 km zone, the radionuclide composition of precipitation is now presented by ^{137}Cs, which accumulated in a condensation form. This form is practically completely soluble and the mobility of ^{137}Cs is determined by its interaction with the soil and the transformation of the forms of connection with it. Soils are among the main objects where ^{137}Cs radionuclides are concentrated to this day. They migrate intensively from the soil and accumulate in plant and animal products, and subsequently enter the human body.

Radionuclides of caesium and strontium are rather tightly bound to the soil. The main part of them – 90–97% is concentrated as in previous experimental periods in the upper 20–25-centimeter layer of meadow soils and in the arable layers of soils of all types (Prister et al., 1992).

The most polluted residential places identified in our study were situated in Narodychi and Ovruch districts, and belong to the zone of unconditional (mandatory) resettlement. Within the zone of guaranteed voluntary resettlement, the most polluted soil was in the Korosten district. That is, despite the fact that the half-life of the radonuclide has practically been completed, the soils of the investigated areas still remain contaminated.

The analysis of the calculated CT of ^{137}Cs, according to the data obtained in the three northern districts of Zhytomyr region showed that beans, table beets and carrots were the most critical regarding the accumulation of ^{137}Cs. This is somewhat contradictory to the data obtained earlier, since the CT obtained for table beet and carrot exceeds the data obtained by previous researchers (Prister et al., 1992, Handl et al., 2003). The highest CT of ^{137}Cs was obtained in all three districts, these were the villages Obykhody in Korosten district, Vystupovychi in Ovruch district and the small town Narodychi. The average CT of ^{137}Cs in beans was recorded at 0.20, which completely coincides with and confirms the data obtained earlier (Strand et al., 1996, Hinton et al., 2007). Thus, the research conducted shows that different types of plant

products absorb and accumulate ^{137}Cs with different intensities, which can be explained by the peculiarity of their mineral nutrition. For the population living on radioactively contaminated territories, plant products grown on private plots have been and still remain the main source of ^{137}Cs radionuclides entering the body.

Sources from the literature indicate that on the basis of long-term research, scientists have established a linear relationship between the content of ^{137}Cs in agricultural crops and the density of soil contamination and the plant species concerned when accumulating these radionuclides. This is also confirmed by the results of our research. Thus, the radiation situation in the contaminated areas is first of all determined by the intensity of the inclusion of radionuclides in the trophic chain, which depends on the type of soil and technological and environmental conditions of production.

Under new conditions, the bulk of products, at least 90%, are produced by farmers and land owners. It is necessary to provide each one of them with accurate information on levels of pollution and ecological properties of soils. New landowners should take the initiative and collect information on the density of soil contamination, products of plant and animal origin from the state authorities and previous landowners. Such information should be obtained and summarized annually.

Conclusions

Soils of agricultural landscapes are one of the main objects where radionuclides of ^{137}Cs are concentrated. They are intensively transferred from the soil into biogenic migration through trophic chains and are accumulated in products of plant and animal origin and subsequently enter the human body. Settlements within Narodychi and Ovruch districts, which belong to the zone of unconditional (mandatory) resettlement, turned out to be the most polluted; these are the villages Vystupovychi, Loznytsia and Khrystynivka, where the density of pollution varied in the range 454.0–401.8 kBq/m^2. Within the zone of guaranteed voluntary resettlement, the most polluted soil was in Korosten district, where the density of pollution sometimes reached 239.7 kBq/m^2 (village Bekhy). It was found that the most critical product, which recorded the highest specific activity of ^{137}Cs, was beans. Excess of the maximum permissible level of specific activity of ^{137}Cs in beans was registered in 4 settlements, which belong to the second zone: in the villages Loznytsia – 82.6 Bq/kg, which is 1.64 DR, Khrystynivka – 77.4 Bq/kg, which is 1.54 DR, Selets – 61.1 Bq/kg, which is 1.22 DR and the small town Narodychi – 54.2 Bq/kg, which is 1.1 DR – 2006. The analysis of calculated CT of ^{137}Cs according to the data obtained in the three northern districts of Zhytomyr region showed that beans, table beets and carrots were the most critical products regarding the accumulation of ^{137}Cs. The highest CT of ^{137}Cs was obtained in all three districts – the villages Obykhody in Korosten district, the village Vystupovychi in Ovruch district and the small town Narodychi. The average CT of ^{137}Cs in beans was recorded at the level 0.20.

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