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RADIONUCLIDE CONTENT IN VEGETATION AND SOILS IN THE IMPACT ZONE OF THE RAILWAY TRACK

Purpose. To identify the harmful radiation impact of railway transport on the environment.

Methodology. In order to determine the level of radioactive contamination in the impact zone of the railway, soil and plant samples were collected, and relevant radiometric studies were carried out in accordance with the established and approved methods. The peculiarities of the accumulation capacity of plants and soil were investigated and graphical models of radionuclide migration on the Lviv-Sambir railway section were created.

Findings. Measurements of the specific activity of ^{90}Sr and ^{137}Cs in plant samples along the railway track showed that grass plants have a lower content of radionuclides and trees have a higher one. It was found that among the herbaceous plants, the species *Galium odoratum* (L.) Scop. accumulates radionuclides ^{90}Sr most intensively, *Geum urbanum* L. accumulates ^{137}Cs. These plants can be used as indicators of the territory contaminated with radionuclides. The highest content of radionuclides in tree species is observed in the leaves of grey alder and oak bark. The highest content of K 40 was observed at a distance of 200 m from the railway track, and the lowest content of Th 232 was observed at a distance of 100 m from the railway track.

Originality. The results of the research showed a significant variation in the content of radioactive substances in the soils of protective forest plantations. This variation in soil contamination can be explained by the heterogeneity of the above-ground cover and the local impact of plantations on the contaminants' airborne transport rate.

Practical value. Taking into account the fact that the concentration of radionuclides in plants and soil decreases away from the railway tracks, we can state that protective forest plantations delay the spread of the existing radionuclide content to the territories adjacent to the tracks.

Keywords: *railway transport, radioactive contamination, environmental safety, afforestation, civil protection*

Introduction. The railway transport sector in Ukraine is the leading one in the transport system with regard to the volume of carried freight. It represents more than 57 % of the country's domestic freight turnover and a significant share of foreign transport. However, rail transport can have a negative impact on adjacent natural ecosystems due to emissions of harmful substances from both rolling stock and transported goods. The study on the patterns and peculiarities of railway transport's impact on the adjacent territories is undoubtedly a relevant subject for assessing and forecasting the state of the environment and developing environmental protection measures in these areas. These issues are becoming extremely relevant in the context of Ukraine's integration into European structures, which require accelerating the social, economic, and environmental development of the transport sector [1].

Literature review. A significant number of research studies of scientists are devoted to the study on the chemical, noise, electromagnetic impact of railway transport on the environment (O. I. Rybina, A. Matveeva, O. Burmas, N. Lukyanchuk, O. Pavlishyna, etc.), while the radiation impact from the railway remains insufficiently studied [2, 3].

Unsolved aspects of the problem. The transportation of rocks with a high natural radiation background (granite, quartz porphyry, quartzite, clay shale, bauxite, marl, basalt, etc.) and violation of environmental requirements for the management of radioactive hazardous substances are crucial for radiation contamination of protective railway strips. The transport of these rocks may release hazardous dust into the air, settle on the ground and vegetation, and cause radionuclides migration in the environment. Hazardous substances dispersed along railway tracks can contribute to the emergence of elevated and abnormal concentrations in the depositing media (soil, plants). Radionuclides can saturate and contaminate the soil environment. Green plantings also have the ability to accumulate up to 90 % of radioactive particles from the growing environment, which can spread further along the trophic chains [4]. The significance of the problem can be realised if we take into account the fact that the total area of protective forest plantations of the Lviv Railway is 240 km², and the area of forest protection plantations on the Lviv-Sambir railway line is more than 14 km², which is 5.8 % of the total area of protective plantations of the Lviv Railway.

Purpose. The aim of the study was to determine the level of specific activity of radionuclides in soils and plantations along the Lviv-Sambir railway line. For reducing the harmful impact of railway transport on the environment, ensuring environmental safety in transport and efficient use of natural resources, railway enterprises annually develop and implement a number of measures that have an environmental effect. Particular attention is paid to protective forest plantations along the railway tracks, as they are an effective tool used to reduce the negative impact of the railway on the surrounding areas. First of all, forest plantations along the railway track are part of a railway engineering complex that protects railway tracks from snow and sand during blizzards or strong winds, and significantly reduces aerodynamic wind resistance to train traffic. Also, forest plantations are part of the environmental protection complex of Ukraine, which fulfils its socio-economic function, namely protecting the surrounding areas from the harmful effects of railway transport and the consequences of possible accidents [5, 6]. Through the transformation of air flows, forest plantations play an important role in the formation of pollution fields by influencing the deposition of aerosol particles. They act like filters – accumulators of heavy metals and radionuclides [7]. Forest biogeocenoses are characterized by the largest biomass per area unit, so the forest retention factor of global fallout varies between 50–100 %, with the retention factor being higher in young pine forests, lower in middle-aged pine forests, and even lower in leafy plantations, and decreasing to 20–25 %.

The impact of ionizing radiation on plants is dependent on the level of the radiation source and the duration of its effect on plants. It is known about acute and chronic effects of ionizing radiation on plants. In case of acute irradiation, the organism receives a dose of radiation during a relatively short period of time, after which it is no longer at risk of the appearance of new radiation lesions, and the development of radiation lesions occurs in conditions favourable for the development of plants [8]. Doses of radiation, irradiation over 0.02–0.05 Gy/day do not affect forest vegetation. For example, at a dose rate of 0.1–0.2 Gy/day, the needles of *Pinus sylvestris* L. begin to turn red, turn brown, and then fall off. Absorbed radiation doses of 0.05–1 Gy/day (over $3.5 \cdot 10^2$ Gy/year) can lead to the death of most plant communities. An absorbed dose of radiation exceeding 1 Gy/day can cause the death of plants, and at 5 Gy/day (more than $3.5 \cdot 10^4$ Gy/year) plants die [9, 10].

Scientists discovered plants that are resistant to radiation [11, 12]. The evergreen shrub *Calluna vulgaris* (L.) Hill is the most resistant to the effects of radiation and the herbaceous plant *Carex pilosa* Scop., in which a significant part of the plant is placed underground and forms fast-growing and rooted shoots after the cessation of radiation. More effective in this regard is the herb *Panicum sanguinale* L., which forms thick thickets under continuous radiation exposure with an absorbed dose power of more than 10 Gy/day [13].

Methods. The investigation was carried out on the Lviv-Sambir railway line, which is located within the main railway line of western Ukraine and serves the main international trade flow of Ukraine with the Czech Republic, Slovakia, Hungary, and Austria. This 73 km long line is single-track, electrified and has significant traffic congestion. The majority of the track runs through non-residential areas, within forest ecosystems and agrocenoses, except for the urban areas of Lviv, Rudky, and Sambir and the areas of 10 village communities (Fig. 1).

The climate of the territory is temperate continental, with mild winters and wet, long springs, warm, rainy summers, and relatively dry, warm autumns. The territory belongs to the zone of excessive humidity, although there are often cases of periodic droughts. In general, it can be stated that the territory is

Fig. 1. Geographical location and sampling points of the Lviv-Sambir railway line

favourable for the growth of forest plantations consisting of deciduous trees such as oak, hornbeam, alder, birch, aspen, ash, maple, poplar, linden, beech, and conifers such as pine, spruce, fir, and larch.

The terrain is predominantly hilly with a height of 300–400 m, with some valleys. The surface of the territory is inclined to the south and southeast, and its southern part is densely dissected by numerous tributaries of the Dniester. In terms of geological and structural features, the study area belongs to the Precarpathian artesian basin. There is a homogeneity of hydrogeological conditions of aquifers with high mineralization in the area. There is a significant difference in the impact of hydrogeological conditions between flat and hilly areas. Groundwater is at the level of 1.5–3 m. The soil cover of the territory is dominated by grey and light grey podzolized soils with a shallow humus horizon of 10–12 cm and a humus content of 3 %. The soils that are common here were formed under waterlogged conditions and are classified as fresh. Such soils are more likely to accumulate hazardous pollutants.

We analysed plant material and soil for radionuclides to determine the level of contamination of the territory with radioactive substances. Samples were taken at various distances from the probable contamination source: 250 m from the track for determination of the background radionuclide content; and sequentially at 200, 150, 100, 50, 30, 15, 10 and 5 m from the track. A total of 9 plots were examined, 500 m long each, along the railway line. On each of the plots, 200 g of phytomass of dominant grass species was collected and used for radionuclide content analysis. Leaves in the amount of 200 g were collected in different parts of the crown and the bark layer was cut off at a height of 1.5 m to analyse the radionuclide content in woody and shrubby plants. Soil samples were collected using the "envelope" method at five points of a square with sides of 100 m in the corners and in the centre. A surface soil layer of 15×15 cm^2 was collected at a depth of 5 cm [14]. The total weight of the average soil sample was at least 1 kg, with vegetation removed beforehand. The collected samples were stored in a dry, dark, and well-ventilated place until the start of work in the laboratory.

The determination of the specific activity of radionuclides is based on the recording of continuous spectra that differ from each other in shape and location in the energy scale. The energy interval method is used to process them for determining the activity of individual nuclides. The spectrum of a sample containing a mixture of several known nuclides is decomposed into the spectra of samples certified for activity and measured under conditions close to the conditions of the test sample [15].

Experimental studies were carried out as described in the "Methods for performing measurements using scintillation spectrometers and software AK 1 No. MI 12-08-99" [16]. Research instruments used in the study included a scintillation spectrometer of beta radiation energies SEB-01-150. The methodology is aimed at express monitoring of specific activity of radionuclides in plants, where radioactive equilibrium disturbance is possible both at the growth stage and in the process of sample preparation for measurement. The methodology determines the specific activity of radionuclides in biota samples, in this case plants, with a basic relative error of ± 10 %. The error for a particular measurement depends on the activity of the sample, the ratio of radionuclides in it, the measurement time, and other factors.

Soil radiation contamination was measured using an ADANI RUG 91-2 gamma radiometer and a Soeks environmental tester [17]. The content of radium ^{226}Ra, thorium ^{232}Th, and potassium ^{40}K was determined in the selected soil samples. The effective total specific activity A_{ef} of natural radionuclides was determined according to the formula

$$A_{ef} = A(\text{Ra}) + 1.31A(\text{Th}) + 0.085A(\text{K}), \qquad (1)$$

where A(Ra), A(Th), A(K) stand for specific activity of Ra 226, Th 232 and K40; 1,31; 0,085 – weighting coefficients relative to Ra 226, Th 232 and K 40.

Results. The first plantations of forest species on the Lviv-Sambir railway section were made in 1960–1970. These were mainly fast-growing species (poplar, ash, hornbeam), although the type of forest vegetation – fresh hornbeam oak forest – is favourable for the growth of the main forest-forming species – common oak. Currently, the green plantations adjacent to the track section are in a relatively satisfactory condition, composed of pedunculate oak (*Quercus robur* L.), black poplar (*Populus nigra* L.), silver birch (*Betula pendula* L.), Tatar maple (*Acer tatricum* L.), hornbeam (*Carpinus betulus* L.), grey alder (*Alnus incana* L.), and common ash (*Fraxinus excelsior* L.). Associated species that contribute to better growth of the main species and better protection include sweet cherry (*Prunus avium*), common aspen (*Populus tremula* L.), wych elm (*Ulmus glabra* Huds.), Northern European hawthorn (*Crataegus oxyacantha* L.), rowan *(Sorbus aucupartia* L.). In the understory grow common hazel (*Corylus avellana* L.), fly honeysuckle (*Lonicera xylosteum* L.), Warted spindle (*Euonymus verrucosa* Scop.) [18].

The main dominants of the herb layer include ground elder (*Aegopodium podagraria* L.), asarabacca (*Asarum europaeum*), greater stitchwort (*Stellaria holostea* L.), sweet woodruff (*Galium odoratum* (L.) Scop.), wood sorrel (*Oxalis acetosella* L.), lady fern (*Athurum felix-femina* (L.) Roth ex Mert.), wood avens (*Geum urbanum* L.), common hepatica (*Hepatica nobilis* L.), annual meadow grass (*Poa annua*), angular Solomon's seal (*Polygonatum officinale* L.), male fern (*Dryopteris filix-mas* (L.) Schott), wood horsetail (*Equisetum sylvaticum*), moneywort (*Lysimachia nummularia* L.), yarrow (*Aciellea submillefolia* L.), common nettle (*Urtica dioica* L.), heath speedwell (*Veronica officinalis* L.), quaking sedge (*Carex brizoides* Juslen), cowslip (*Primula officinalis* Hill), ground-ivy (*Glechoma hederacea* L.), red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), common dandelion (*Taraxacum officinale* Wigg), tufted vetch (*Vicia cracca* L.).

Based on the results of ^{90}Sr and ^{137}Cs measurements in the herbal raw material samples, it was found that the average experimental samples had a low content of radionuclides (Table 1).

According to the conducted research, the content of ^{90}Sr and ^{137}Cs radionuclides does not exceed the maximum permissible level. However, the content of radionuclides varies depending on the sampling location. The highest radionuclide content was observed in the grass cover samples taken at a distance of 5 m from the track, with ^{90}Sr content of more than 34.9 Bq/kg and ^{137}Cs content of 29.0 Bq/kg. Fig. 2 shows 3D modelling of ^{90}Sr and ^{137}Cs radionuclide spread along the Lviv-Sambir railway track depending on the sampling point.

The investigation also showed that not all types of grass cover have the same ability to accumulate radionuclides. In particular, the species *Galium odoratum* (L.) Scop. accumulates ^{90}Sr radionuclides the most – 17.0 Bq/kg, while *Aegopodium podagraria* L. accumulates only 2.10 Bq/kg. Also, the species *Geum urbanum* L. accumulates ^{137}Cs the most among others – 17.0 Bq/kg. Therefore, these plants can be used as indicators of the radionuclide-contaminated area.

The study of radionuclide content in the leaves of shrubs of protective forest plantations showed that the samples have low content of ^{90}Sr and ^{137}Cs radionuclides (Table 2). The highest accumulation of radionuclides in comparison with other species is observed in fly honeysuckle (*Lonicera xylosteum*): ^{90}Sr – 21.4 Bq/kg, ^{137}Cs – 14.9 Bq/kg.

The research has confirmed that the content of radionuclides in trees is much higher than in shrubs and herbs. Trees accumulate more ^{137}Cs than ^{90}Sr, in contrast to shrubs and grasses. Therefore, it can be concluded that in case of an emergency, tree species may be most affected (Fig. 3).

The study on the content of radioactive ^{90}Sr and ^{137}Cs in tree bark afforestation also showed that it does not exceed the permissible content standards. The highest content of ^{90}Sr was detected in *Alnus incana* (over 45.3 Bq/kg), and ^{137}Cs in *Quercus robur* L. (over 48.6 Bq/kg) (Fig. 4).

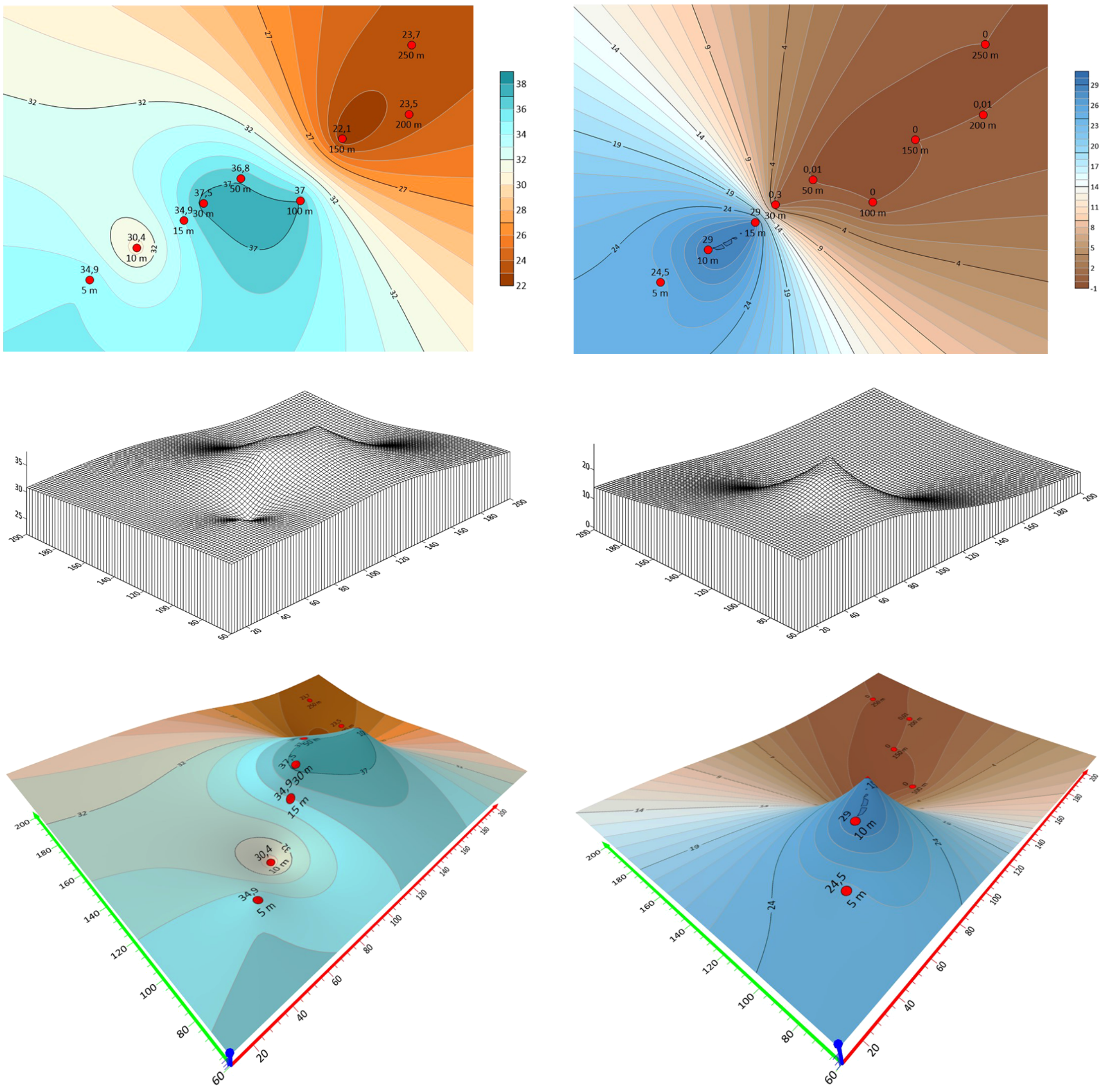
The content of radioactive ^{90}Sr and ^{137}Cs is not an influential factor determining the growth conditions of a forest plantation. The highest content of radionuclides is observed in tree species, namely in leaves and bark. The highest content of ^{90}Sr is 51.3 Bq/kg, and ^{137}Cs is 58.8 Bq/kg in leaves and bark, respectively; ^{90}Sr is 45.3 Bq/kg and ^{137}Cs is 48.6 Bq/kg. The determination of radionuclide content in tree leaves showed that the content of ^{90}Sr and ^{137}Cs did not exceed the established maximum permissible emission limits. The highest content of ^{90}Sr in the tree bark compared to other species is accumulated by alder (51.3 Bq/kg), and ^{137}Cs – by oak *Quercus robur* L. (58.8 Bq/kg).

Thus, the study in the forest protection belts of the railway on the Lviv-Sambir railway line showed that the content of radionuclides in plants is within the maximum permissible limits. This is important for the further economic activity and sale of wood raw materials by the Ukrzaliznytsia unit that manages the protective forest plantations. While maintaining the pro-

Table 1

Specific activity of ^{90}Sr and ^{137}Cs in averaged samples of herbal raw materials, Bq/kg

	Distance from the track, m									MPC, Bq/kg
	250 (background)	200	150	100	50	30	15	10	5	
^{90}Sr	23.7	23.5	22.1	37.0	36.8	37.5	34.9	30.4	34.9	100
^{137}Cs	0.00	0.01	0.00	0.00	0.01	0.30	29.0	29.0	24.5	200



a *b*

Fig. 2. 3D modelling of radionuclide distribution (Bq/kg) along the Lviv-Sambir railway line:
a – ^{90}Sr; b – ^{137}Cs

tective forest belts of the Lviv railway, the track maintenance department carries out annual forest management activities. Sanitary felling, maintenance and reconstruction felling, felling of hedges and shrubs to restore and clear sight lines on the tracks generate large quantities of wood raw materials, which are later sold commercially. Income from timber and wood materials sales is used by Lviv Railway to cover part of its costs, namely land use fees, general and administrative expenses, and employee salaries [19].

Measurements of radium, thorium, and potassium radionuclides in the soil showed that regardless of the distance of the sampling site, all soil samples have low levels of radionuclides. The highest content of ^{40}K was observed at a distance of 200 m from the track, and the lowest content of ^{232}Th was observed at a distance of 100 m from the track surface. Fig. 5 shows 3D modelling of ^{226}Ra, ^{232}Th, ^{40}K activity distribution in soil along the railway on the Lviv-Sambir track line.

Radionuclides released into the soil during railway transport operations do not affect the radiation status of the

Table 2

Specific activity of ^{90}Sr and ^{137}Cs in the leaves of shrub plants

Plant name	Specific activity content of radionuclides, Bq/kg	
	^{90}Sr	^{137}Cs
Corylus avellana L.	14.1	10.0
Euonymus verrucosus Scop.	20.5	10.0
Lonicera xylosteum L.	21.4	14.9

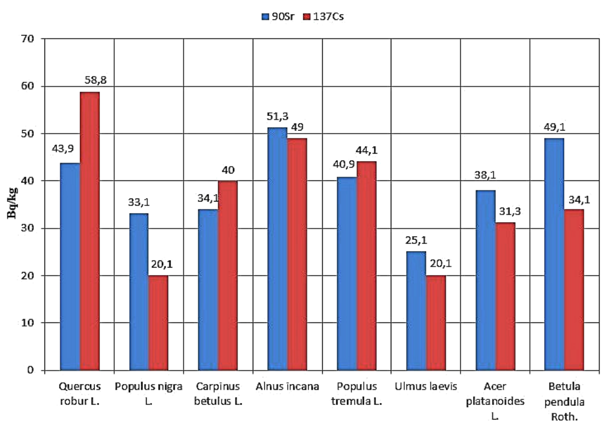


Fig. 3. Radionuclide content in the leaves of the studied tree species along the Lviv-Sambir railway line

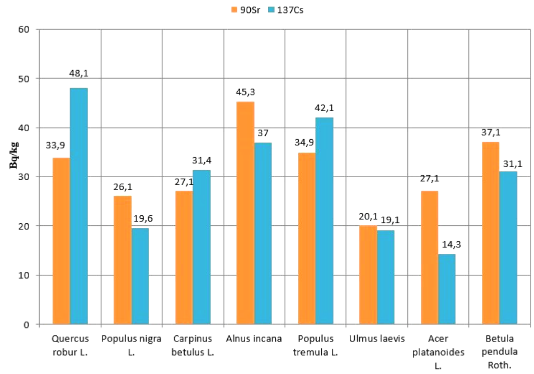


Fig. 4. Radionuclide content in the bark of the studied tree species along the Lviv-Sambir railway line

adjacent territories. Thus, the adjacent agricultural cenoses and residential buildings adjacent to the railway, uncontaminated with radionuclides, are not at risk of radiation contamination.

The results of the soil radionuclide measurements showed that the total specific activity of natural radionuclides decreases by almost 2 times with the distance to the contamination source (Table 3). Thus, we can state that green protective plantation reduces the spread of radionuclides.

According to DSTU-N B A.3.2-1:2007 [20], regulating permissible levels of radionuclides, the effective total specific activity A_{ef} of natural radionuclides ^{226}Ra, ^{232}Th, ^{40}K determined in the soil belongs to Class I, i. e. $A_{ef} < 370$ Bq/kg. Soil specific activity measurements showed that radionuclides released into the soil during railway transport activities were so

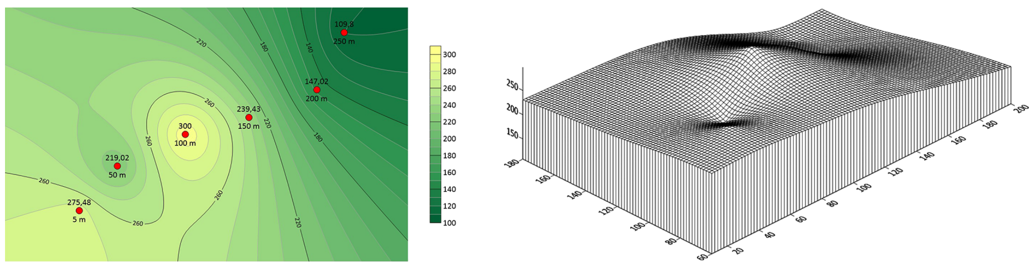
Table 3

Dependence of the effective total specific activity A_{ef} of natural radionuclides

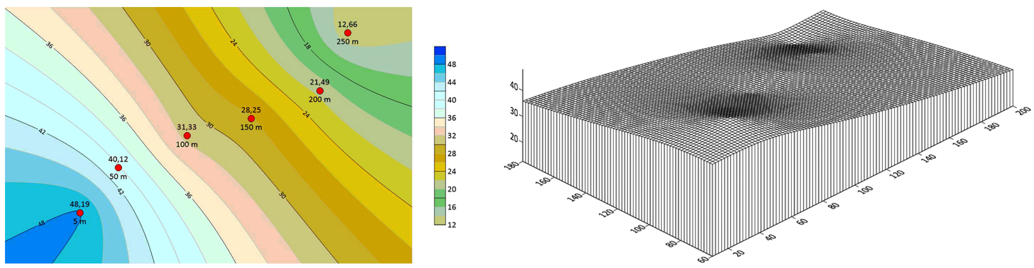
Distance from the railway track, m	A_{ef}, Bq/kg
5	90.39
50	86.86
100	76.76
150	63.42
200	45.78
250	42.76

low that they did not affect the radiation status of the adjacent territories.

Conclusions. A study on the content of radioactive substances in protective forest plantations on the Lviv-Sambir railway line found that the specific activity of radionuclides in plants and soil is safe for adjacent agricultural communities and residential buildings and does not exceed the maximum permissible levels. This makes protective plantations not only environmentally necessary, but also economically viable and profitable, and allows us to generate significant income from the sale of harvested wood. Taking into account the fact that protective forest plantations along transport routes are a reliable and long-term biological means of protecting railway tracks from the negative effects of natural phenomena, the task of protective forest plantations ("Ukrzaliznytsia") is currently to ensure their maintenance in proper conditions and functioning as a protective function.



a



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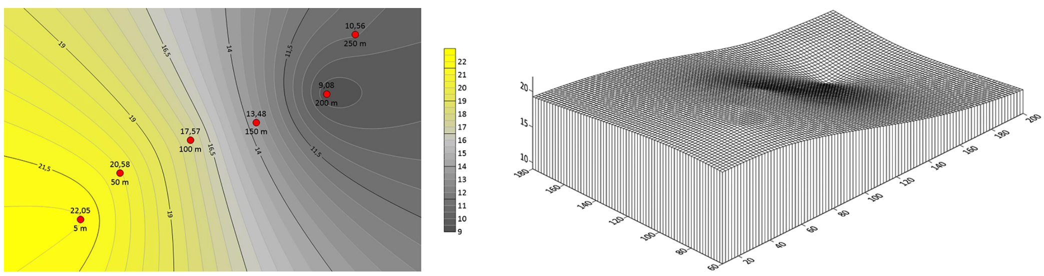

c

Fig. 5. 3D modelling of radionuclide activity distribution in the soil (Bq/kg) along the Lviv-Sambir railway: a – K 40; b – R 226; c – Th 232

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Вміст радіонуклідів у рослинності та ґрунтах у зоні впливу залізничного транспортного шляху

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Мета. Полягає у виявленні шкідливого радіаційного впливу залізничного транспорту на довкілля.

Методика. Для визначення рівня радіоактивного забруднення в зоні впливу залізниці було здійснено відбір проб ґрунту та рослинних зразків і проведені відповідні радіометричні дослідження відповідно до встановлених і затверджених методик. Досліджені особливості акумулюючої здатності рослин і ґрунту та створені графічні моделі міграції радіонуклідів на ділянці колії Львів-Самбір.

Результати. Вимірювання питомої активності радіонуклідів ^{90}Sr і ^{137}Cs у зразках рослин уздовж залізничного шляху засвідчило, що менший вміст радіонуклідів є у трав'яних рослинах, вищий вміст – у деревних порід. Виявлено, що із трав'яних рослин найбільш інтенсивно серед усіх інших накопичує радіонукліди ^{90}Sr вид *Galium odoratum* (L.) Scop., найбільше серед інших накопичує радіонукліди ^{137}Cs вид *Geum urbanum* L. Ці рослини можна використовувати в якості індикаторів забрудненої радіонуклідами території. Найбільший вміст радіонуклідів деревних порід спостерігається в листі вільхи сірої та корі дуба. Найбільшим вмістом відзначається K 40 на відстані 200 м від колії, а найменшим вмістом – Th 232 на відстані 100 м від колії залізничного шляху.

Наукова новизна. Результати досліджень засвідчили значну варіабельність вмісту радіоактивних речовин у ґрунтах захисних лісонасаджень. Таку варіацію забруднення ґрунту можна пояснити неоднорідністю надґрунтового покриву й локальним впливом насаджень на швидкість повітряного переносу забруднюючих речовин.

Практична значимість. Беручи до уваги те, що концентрація радіонуклідів у рослинах і у ґрунті зменшуються у напрямку від залізничної колії, то можемо стверджувати, що захисні лісонасадження затримують поширення існуючого вмісту радіонуклідів на прилеглі до колії території.

Ключові слова: *заліничний транспорт, рідіаційне забруднення, екологічна безпека, лісонасадження, цивільний захист*

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