

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Rimantas BEINARAVIČIUS

**INVESTIGATION AND FORECAST OF VARIATION OF
LONG-TERM SOIL CONTAMINATION WITH
RADIONUCLIDES ACCORDING TO THEIR
ACCUMULATION IN TREE SEGMENTS**

Summary of Doctoral Dissertation

Technological Sciences,
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VILNIUS GEDIMINO TECHNIKOS UNIVERSITETAS

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**DIRVOŽEMIO ILGALAIKĖS UŽTARŠOS
RADIONUKLIDAIŠ KAITOS TYRIMAS IR PROGNOZĖ
PAGAL JŲ KAUPIMĄSI MEDŽIŲ SEGMENTUOSE**

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General Characteristic of the Dissertation

The problem

The development of mankind is inevitably related to the ever increasing impact on nature. During recent decades due to scientific and technical advances, human possibilities of influencing the nature began to substantially exceed our ability to understand, evaluate and forecast consequences of this activity, quite often unexpected and unacceptable. With the nuclear technology development, along with other problems there occurred the problem of the environment contamination with radioactive substances. Their consequences are felt over many years, and radionuclides having penetrated into the environment take part in the exchange processes between various natural media, migrate over long distances, get into biological objects and accumulate in them.

Previously, especially after the Chernobyl nuclear power plant (NPP) accident, and currently most attention both in the world and in Lithuania is paid to the investigations of specific activity of radioactive substances in the environment. However, there are a lot of problems of evaluating their biological danger, accumulation, migration and withdrawal in the environment from different environmental objects as well as of forecasting these processes.

From the atmosphere radioactive substances are withdrawn with dust, they can be washed out with precipitation and decrease during radioactive decay. Radionuclides deposited to the ground surface are absorbed by soil and vegetation.

Topicality of the subject

After some time following the global depositions and pollution after the Chernobyl NPP accident, Lithuanian soils are most contaminated with ^{137}Cs and ^{90}Sr .

In the work the ^{137}Cs accumulation as well as vertical and horizontal migration in soil have been evaluated. The specific activity of the artificial origin ^{137}Cs in tree segments has been determined, coefficients of its transfer from soil to various parts of the woody plant have been evaluated and compared with the transfer of the natural origin radionuclide ^{40}K .

The radionuclide accumulation both in soil and plants, wash-out from the environment and radioactive decay last for years, therefore it is expedient to choose proper methods and evaluate tendencies of the long-term contamination variation. Radionuclides having penetrated into the environment are accumulated in the vegetative ground cover and upper soil layer. Their accumulation in plants occurs directly from the atmosphere through their above-ground parts, while from leaves, branches and sprays as well as root surface radionuclides get into plant tissues and join the biological metabolism. These processes have not been evaluated sufficiently yet, though it is important from both biological and environmental point of view. After evaluating the radionuclide penetration into trees through their above-ground part and roots, radionuclide accumulation and distribution in a tree

can be modeled and forecasted as well as a reverse task can be solved – their volume activity at any soil depth can be determined according to the radionuclide specific activity in the tree ring of the corresponding year.

Objectives of the work:

To determine the accumulation of the artificial radionuclide ^{137}Cs in soil and a tree, to define coefficients of transfer from soil to various woody parts of plants.

To forecast the variation of the long-term soil contamination with radionuclides according to their accumulation in tree parts.

To develop the model of radionuclide transfer in the system “soil–tree”.

Tasks of the work:

- To apply the methods of sample collection and their preparation for radiometric measurements and implement the intended equipment.
- To master and apply the methodology of determining the ^{137}Cs specific activity in wood.
- To determine the dependence of radionuclide specific activities in tree rings on the pollution density at different soil depths, the type of soil, chemical composition, precipitation amount and other factors.
- To determine the distribution of the ^{137}Cs specific activity in the vertical soil profile and tree segments.
- To define more precisely the distribution of the radionuclide volume activity in soil determined by the method of “tree rings” by modeling their migration in the system „soil–tree”.

The novelty of the work

- The radionuclide penetration into trees not through their external above-ground part but also through the roots has been evaluated. According to the investigation results the radionuclide accumulation in trees can be determined, and the absorbed dose, by which trees were irradiated not only externally but also in their segments during separate periods, can be forecasted.
- According to the radionuclide accumulation in tree rings the soil contamination during separate years has been modeled and forecasted as well as the surface density of radioactive depositions has been determined.
- The accumulation of natural and artificial origin radionuclides in soil in the tree influence zone has been determined.
- The model enabling evaluation of the radionuclide migration in soil under the tree crown has been developed, and the characteristic of the pine (*Pinus sylvestris* L.) and a birch (*Betula pendula* L.) to accumulate radionuclides has been evaluated.

- The method of the tree ring separation using chisels–choppers has been improved.

Practical significance of the work

According to the obtained results the absorbed radiation doses in woody plants of the investigated region during different pollution periods can be evaluated. Referring to the research results, the radionuclide exchange in the system “soil–tree” can be determined. The interruption of this exchange and the distribution of radionuclides appearing due to human activity using wood in construction and furniture industry can be evaluated. Data on the radionuclide accumulation in various trees can be useful in investigating the tree upgrowth and spreading of tree diseases. Moreover, in future referring to the results of the work, human exposure using wood in domestic and industrial premises can be evaluated. This work is also significant because after determining coefficients of its transfer from soil of various types to woody plants the total amount of artificial origin radionuclide ^{137}Cs accumulated by the forest system of Lithuania and its regions can be evaluated.

Approbation of the work

The dissertation results were reported at four international and six republican scientific conferences. On the subject of the dissertation 2 scientific papers were published in foreign peer-reviewed journals (one in ISI system journal), 3 papers in Lithuanian technical peer-reviewed journals, 1 publication in proceedings of international conferences and 7 publications in proceedings of republican conferences, 1 claim for invention is presented.

Extent and structure

The dissertation includes introduction, 4 main chapters, conclusions of the work, 105 references and a list of 13 publications on the dissertation subject. The dissertation comprises 132 pages, 87 Figures and 12 Tables.

Short content of the dissertation

1. Natural and artificial origin radionuclides in the environment

The Chernobyl NPP accident on 26 April, 1986, had great influence on the spreading of artificial origin radionuclides in Lithuania. Meteorological and synoptic parameters also conditioned the fact that Lithuania was on the direct air mass way from Chernobyl, and on 28–30 April Lithuania was contaminated by air masses “returning” pollutants from Northern and Western countries. Air masses carrying radionuclides from the Chernobyl NPP over the territory of Lithuania spread over its southern, southwestern and western parts. Therefore, on these territories soil contamination with radioactive substances is also the largest. This was confirmed by gamma spectrometric measurements of the Lithuanian territory performed from the plane in 1987, and the ^{137}Cs contamination distribution density ($\text{Bq}\cdot\text{m}^{-2}$) was determined. The ^{137}Cs contamination zones in West and South Lithuania are shown in Fig. 1.1.

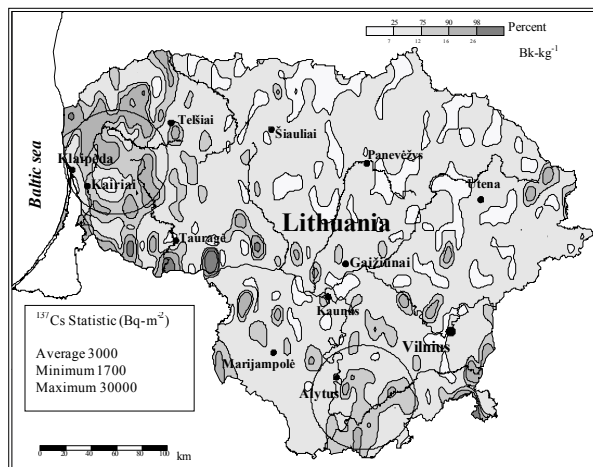


Fig 1.1. Results of gamma spectrometric investigations from the plane

The appearance of radioactive substance “spots” of larger area can be explained by peculiarities of the vertical air mass mixing. Such “spots” were observed near water bodies, in hilly clayey localities and the outer woods, i.e. at such places where the ground heating temperature differed by up to 10°C. These localities are also distinguished by large floor surface “roughness” and increased atmosphere turbulence. Fig. 1.1 presents two zones of the largest contamination with ^{137}Cs in Lithuania: one of them is in the western part of Lithuania, conditionally called the Klaipėda zone, and another in the southern part near Alytus.

Out of artificial origin radionuclides, plants best absorb ^{137}Cs . After some years following the deposition, the absorption of the artificial origin radionuclide ^{137}Cs into a tree begins to decrease, and only after 9–15 years following the deposition plants begin to absorb the radionuclide through roots.

Having penetrated into the forest ecosystem radionuclides accumulate in it and with timber they can induce human exposure.

2. Methodology of experimental investigations

2.1. Selection of trees and growth place for the investigation

In 2000 samples were collected in the areas most contaminated with ^{137}Cs (“spots”): in southern and western regions (marked by circles in Fig. 1.1).

Soil samples were taken from different growth places of two birch trees (*Betula pendula* L.) and three pine trees (*Pinus sylvestris* L.): under the pines of the ~30–40 m height, 0.4–0.45 m thickness, 52–56-years (1P, 2P, 3P) and the birches

of the 23 m height, 0.3–0.45 m diameter, 52–58-years (1B, 2B) in the southern contamination zone in Lithuania. The site selected for the investigation is in the region of increased contamination with ^{137}Cs because in soil of this type in uncontaminated regions the ^{137}Cs specific activity does not exceed $10 \text{ Bq}\cdot\text{kg}^{-1}$.

The other site, where samples of soil and of the 35-year old birch (3B) were collected, is the birch growth place in the west Lithuania, in the coastal contamination zone.

After the Chernobyl NPP accident the ^{137}Cs specific activity in the 0–5 cm soil layer on average made up $(48\pm 12) \text{ Bq}\cdot\text{kg}^{-1}$. At present it reaches $(27\pm 12) \text{ Bq}\cdot\text{kg}^{-1}$.

2.2. Soil sampling under the tree crown

In 2000–2003 samples were taken in the areas most contaminated with ^{137}Cs (“spots”): in the southern region (Alytus district) and the western region (Klaipėda district). In each contamination zone the ^{137}Cs specific activity and the surface activity density at the 0–30 cm depth in forest soil as well as its transfer from soil to woody plants, pines (*Pinus sylvestris* L.) and birches (*Betula pendula* L.), were investigated. Soil samples in the forest under tree foliage were collected at the 0 – 30 cm depth every 5 cm.

2.3. Sampling of tree segments for the investigation

Samples of wood were taken after the trees had been stumped because then it is possible to take samples exactly according to the years (rings) as well as their quantity and mass are not limited. When samples of the stumped tree trunk were taken, at first three 5 cm long tree woodblocks were cut at three different heights: 1.3 m from the ground, $\frac{1}{2}$ of the tree height and $\frac{3}{4}$ of the tree height.

The cut woodblock was polished to display the tree annual rings, then the age of the plant was determined and the rings highlighted with a marker. They were chopped according to the rings using a scraper or a corresponding chisel–chopper (of 6, 12, 24, 32, 50, 100, 130, 150, 180 mm depending on the diameter of the tree trunk).

2.4. Determination of radionuclide specific activity in samples

For wood sample burning the furnace CHOJI – 1,6,2,5.1/9–И5 was used. The furnace was equipped with the air pipe, a cowl and a ventilator for smoke removal.

The spectrometer efficiency for the 662 KeV energy was 0.26%, resolution – 4%.

The specific activity of ^{137}Cs and natural origin radionuclides was determined by an equation: $A = (S / t - S_f / S_f) / m \cdot \varepsilon \eta, \text{ Bq} \cdot \text{kg}^{-1}$. (2.1)

where S is the area of the radionuclide activity peak in the measured material, $\text{imp}\cdot\text{s}^{-1}$; S_f is the area of the background irradiation peak, $\text{imp}\cdot\text{s}^{-1}$; t is the sample measurement time, s; ε is the product of energy and geometric efficiencies of the semiconductor spectrometer; η is the quantum yield of the radionuclide decay; m is the mass of the measured sample, kg.

2.5. Evaluation of radionuclide accumulation in different tree segments

For the determination of migration pathways of artificial and natural origin radionuclides, a model, which could evaluate processes indicated in Fig. 2.1, is needed. The essence of the developed model is investigation and forecast of the variation of long-term soil contamination with radionuclides according to the radionuclide accumulation in plant segments. For the evaluation of soil contamination of many years the radionuclide specific activities in tree segments were measured. Referring to the investigation results, the radionuclide migration process in the system “soil–tree” was evaluated.

For the evaluation of the radionuclide transfer from different layers of the (0–30) cm soil depth to thin plant roots, first of all radionuclide specific activities in (0–5, 5–10, 10–15, 15–20, 25–30) cm soil layers were measured, and then the contamination of the (0–30) cm soil layer was estimated, $\text{Bq}\cdot\text{m}^{-2}$.

In the evaluation of ^{137}Cs contamination densities ($\text{Bq}\cdot\text{m}^{-2}$) in different soil layers (0–5,...25–30) cm during the year of the wood ring investigation, equation

$$(2.2) \text{ was used: } Q_{n(0-30)}^n = \left(\left(\frac{Q_s^N}{Q_R^N} \cdot Q_R^n \right) \cdot e^{\lambda t_n} \cdot \frac{Q_s^N}{Q_s^N} \cdot \frac{Q_{n(0-30)}^N}{Q_s^N} \right) \cdot K \cdot \frac{\check{S}M_n}{100} \cdot K_{n(0-30)}, \quad (2.2)$$

where $Q_{n(0-30)}^n$ is the radionuclide activity density in soil layers (0–5,...25–30 cm) during the n year of the wood ring investigation; $\check{S}M_n$ is the distribution of the plant root mass in soil (0–5,...25–30 cm) profile, %; Q_R^n is ^{137}Cs specific activity in wood during the n year, $\text{Bq}\cdot\text{kg}^{-1}$; K is the coefficient evaluating the variation of birch and pine biomass; Q_s^N is the radionuclide specific activity in thick roots during the n year; Q_s^N is the radionuclide specific activity in thin roots during the n year; Q_R^N is the radionuclide specific activity in wood rings during the n year, $\text{Bq}\cdot\text{kg}^{-1}$; $K_{n(0-30)}$ is the corrective coefficient of activity densities in different soil layers; λ is the radionuclide decay constant, m^{-1} ; t_n is the time period from the contamination beginning to the n year, years.

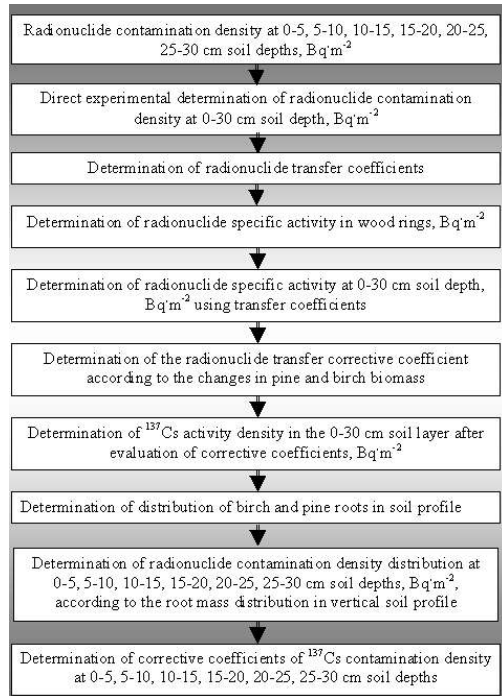


Fig 2.1. Evaluation structure of ^{137}Cs migration process in the system “soil–tree”

2.6. RSP model of radionuclide exchange in the system „soil–tree“

RSP (Radiocological software package) program is intended for modeling the environment protection processes. It was developed for modeling depositions after the Chernobyl NPP accident by determining the radionuclide migration in soil according to the vertical profile. Moreover, using this computer package the radionuclide penetration into plants after some time (month or year) can be modeled. The program was developed by specialists of the Italian environment protection agency (APAT) and San Luis university (UNSL).

3. Research results and their analysis

3.1. Investigations of radionuclide specific activity distribution in soil and a tree

By analyzing the ^{137}Cs distribution in surface soil around trees under the tree crown, it has been determined that in the first and third zones nearest to the trunk the ^{137}Cs specific activity in soil was the largest. The evaluation of contamination in the zone of tree crown influence according to the cardinal points (Fig. 3.1) has

shown that the largest ^{137}Cs specific activity in soil is on the eastern side, which can be caused by meteorological conditions.

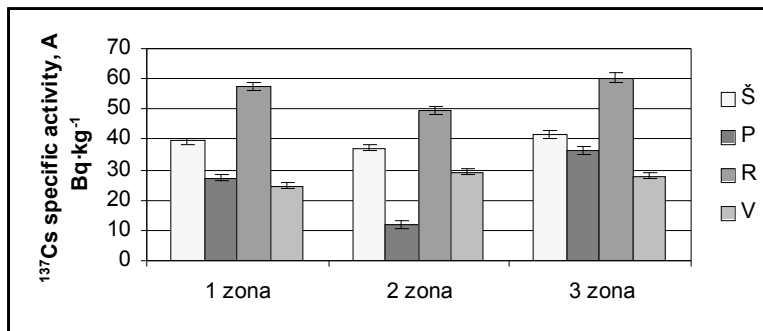


Fig 3.1. Variation of ^{137}Cs specific activity at the 0–5 cm soil depth according to the cardinal points under the crown of a birch which grew in the southern contamination part, $\text{Bq}\cdot\text{kg}^{-1}$: Š–North; P–South; R–East; V–West

In the third zone of the birch influence the ^{137}Cs specific activity in soil could increase because it is the boundary zone adjoining the tree crown edge, the crown is conical, water flows down from it forming a “roof effect”.

By evaluating the total radionuclide ^{137}Cs accumulation in pines which grew in the southern contamination part of Lithuania, it has been determined that it is largest in the first zone and the contamination decreases exponentially from the trunk to the crown edge.

In the western contamination part of Lithuania the largest amounts of the radionuclide were determined at the middle part of the crown. Such different migration of the radionuclide can be explained by different forms of the plant crown and their thickness. Besides, it is observed that in the first and third zones the ^{137}Cs specific activity in soil is larger in the eastern part, while in the second zone – in the southern part. It means that the redistribution of water run-off in the crown takes place.

Based on the data presented in Fig. 3.2 a different ^{137}Cs distribution in wood according to the tree height is observed: the largest specific activity of this radionuclide is determined in the upper part of the pine trunk and in the lower part of the birch wood. In bark of both types of plants (1P, 1B, 2B), ^{137}Cs is accumulated twice as intensively as in wood.

It has been observed that in birch 2B, which grew in the western part of Lithuania, the distribution of the artificial origin radionuclide ^{137}Cs is uniform along the whole height of the plant, which can be consequence of the milder marine climate influence. Moreover, other factors important for the radionuclide

distribution along the plant height are seasonality and the amount of precipitation fallen in the plant zone.

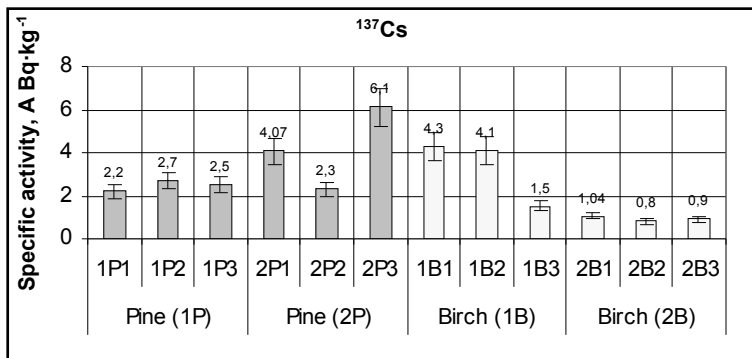


Fig 3.2. Average ^{137}Cs specific activity values in pines and birches: 1P1, 1B1, 2B1 – samples taken 1m from the stump at the trunk height, 1P2, 1B2, 2B2 – samples taken at the $\frac{1}{2}$ of the trunk height, 1P3, 1B3, 2B3 – samples taken at the $\frac{3}{4}$ of the trunk height

It is only observed that the specific activity values of ^{40}K in the birch bark are close to those determined in the lower part of the trunk. The radionuclide values in branches and sprays on average are larger than in wood, but when comparing with the bark of birches and pines the activity on average is 10% lower (Fig. 3.3).

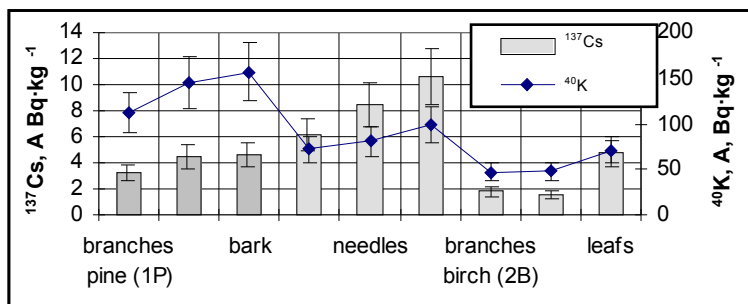


Fig 3.3. Average values of specific activity of the artificial origin radionuclide ^{137}Cs and natural origin radionuclide ^{40}K in birch and pine branches, bark and needles, Bq·kg⁻¹

It has been determined that the accumulation of artificial origin radionuclide ^{137}Cs and natural origin radionuclide ^{40}K in bark and branches of birch 2B is 2–3 times lower than in birch 1B growing in the southern contamination zone.

Radionuclide specific activities, $\text{Bq}\cdot\text{kg}^{-1}$, determined experimentally in pine and birch rings of the n year are presented in Fig. 3.4.

In the birch wood two contamination periods, 1960–1964 and 1986, caused by the nuclear weapon tests and the Chernobyl NPP accident, are evident. In pine, contrary to birch, contamination periods become apparent only after 6–8 years because complete „self-cleaning“ of pine needles lasts about 3–4 years, of birch leaves – 1–2 years.

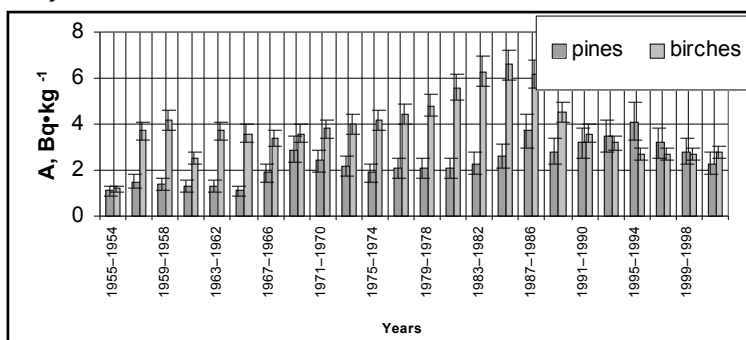


Fig 3.4. Experimentally determined average ^{137}Cs specific activities in pine and birch rings in 1956–2000, $\text{Bq}\cdot\text{kg}^{-1}$

^{137}Cs specific activity and its ratios to the natural origin radionuclide specific activity decrease according to the soil vertical profile. It is seen in Table 3.1 that the penetration of ^{40}K from soil to a tree is similar to that of ^{137}Cs . Despite that, the ratio of the ^{137}Cs and ^{40}K specific activity in wood is larger than in soil (except the 0–5 cm layer) and almost does not change along the trunk height.

Table 3.1. Ratios of ^{137}Cs and natural origin radioisotope specific activities in soil and in wood at various pine heights

	Soil depth, cm					Part of pine trunk		
	(0–5)	(5–10)	(10–15)	(15–20)	(20–25)	1P1	1P2	1P3
$^{137}\text{Cs}/^{226}\text{Ra}$	0.87	0.43	0.11	0.17	0.07	0.324	0.118	0.417
$^{137}\text{Cs}/^{232}\text{Th}$	11.3	0.4	2.86	0.6	0.7	1.375	0.964	1.563
$^{137}\text{Cs}/^{40}\text{K}$	0.07	0.01	0.014	0.01	0.01	0.033	0.032	0.027

3.2. Modeling results of radionuclide migration and accumulation in soil and a tree

Data of the experimental model were compared with the computer RSP (Radiocological software package) program. In modeling vertical variation of the ^{137}Cs activity in soil, two contamination periods of this radionuclide were accepted.

They are the period of nuclear weapon tests in 1955–1963 and the Chernobyl NPP accident in 1986.

In the experimental model, contrary to the RSP model, the soil activity in all layers after the contamination in 1986 decreases exponentially. In the RSP model after 10 years following the deposition in the soil surface at the 0–1 cm depth the soil activity decreases from 2000 to 1300 Bq·m⁻², while to the soil surface depositions makes up 2000 Bq·m⁻².

Non-uniformity of these models can be explained by the fact that in the RSP model the amount of roots and their distribution in soil profile are not evaluated as well as the annual biomass increase is not taken into account.

Another difference between the experimental and theoretical models is that according to the theoretical model radionuclides during 25 years reach only the 15 cm depth, while in the experimental model radionuclide amounts are observed in soil even at the 30 cm depth.

Fig. 3.5 presents the ¹³⁷Cs migration in the soil surface of the pine and birch influence zone, when the deposition density in the computer model over two periods reached 2000 Bq·m⁻², and in the experimental model the experimentally determined soil contamination density in 1955 and 1986 is used.

Data presented in Fig. 3.5 show that during the years of nuclear weapon tests in 1955–1969 the increase of ¹³⁷Cs in soil surface is observed, but after the Chernobyl NPP accident in 1986 a decrease of the artificial origin radionuclide in the influence zones of both the birch and the pine is determined.

The coefficients of ¹³⁷Cs transfer from soil to a tree wood determined experimentally and using the RSP program Fig. 3.6. The transfer coefficient values determined using the RSP program (0.002–0.013)±0.002 are close to the experimentally determined ones (0.001–0.004)±0.001 by evaluating from the tenth year of growth.

It is seen that according to the RSP model the radionuclide transfer from soil to a tree during 25 years has a tendency to decrease because the radionuclide contamination in soil decreases (they decay and migrate to depth) as well as the ability of trees to accumulate radionuclides decreases.

But this model does not evaluate additional contamination of soil (the period 1955–1962) following the main contamination as well as the root distribution in the vertical soil profile, and thereby better conditions of transfer of radionuclides migrating to depth, e.g. down to 25 cm, are not taken into account.

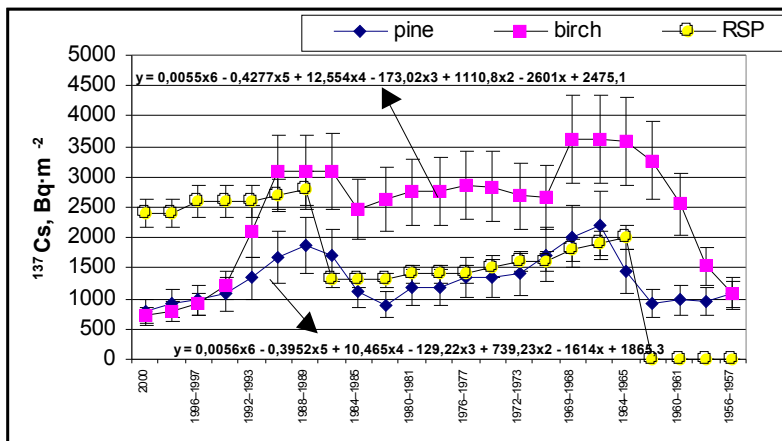


Fig 3.5. Radionuclide migration in the soil surface (0–5 cm) layer according to the experimental and computer models

The experimental model evaluating the coefficient of ^{137}Cs transfer from soil to a tree takes into account the distribution of tree roots, the tree biological reciprocity according to the age and the lag of its accumulation in roots after the soil surface contamination.

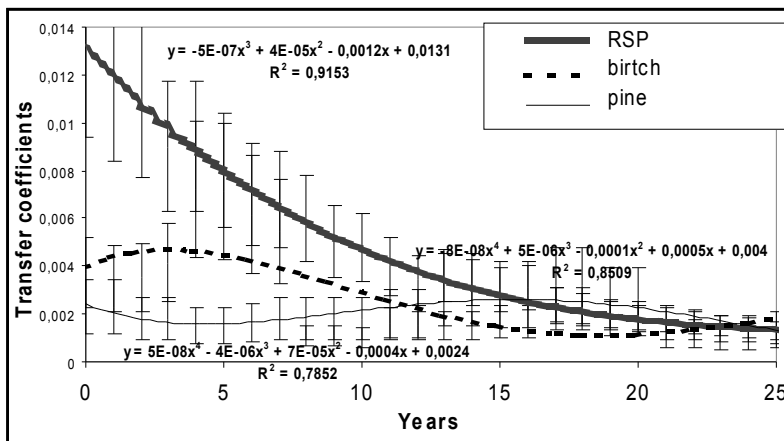


Fig 3.6. Variation of ^{137}Cs transfer coefficients from soil to a tree

4. Used equipment, applied methods and experimental stands

In the work the developed methodology of soil sampling under tree foliage, which enables soil sampling according to the cardinal points and the soil vertical profile, is described. For wood sample burning a standard furnace was improved, equipped with air pipe, cowl and a ventilator for smoke removal.

General conclusions

1. The artificial origin radionuclide ^{137}Cs penetrated into the environment mostly during two contamination periods: during nuclear weapon tests (1945–1980) and after the Chernobyl NPP accident in 1986. The ^{137}Cs contamination “spots” have formed on the ground surface. The largest zones of the contamination with ^{137}Cs in Lithuania are determined in the western part of Lithuania, in the Klaipėda region, and in the southern part, near Alytus.
2. The methodology of taking samples of tree segments (sprays, needles, leaves, trunk), their preparation for radiometric investigations and research has been mastered as well as the equipment has been designed and introduced.
3. According to the radionuclide accumulation in separate tree segments, the experimental model in the investigation of the radionuclide migration in the system “soil–tree” has been developed and applied in practice. By means of the developed model the radionuclide migration in soil under the tree foliage can be determined and the ability of pines and birches to accumulate radionuclides can be evaluated. Using the experimental model the former soil contamination can be reproduced and forecasted.
4. The tendency of the two type ^{137}Cs specific activity increase in a pine and a birch has been observed. A slight ^{137}Cs specific activity increase in the wood of a growing tree after the penetration of this radionuclide from needles and bark was determined in 1955–1980 and 1986, and a more distinct increase after 10 years following the contamination, when radioisotopes penetrated into a tree through its roots.
5. The specific activity of radioisotopes in pine needles and bark is by an order of magnitude larger than in wood because it depends not only on transfer from soil through roots but also the contamination directly from the air. The accumulation of ^{137}Cs and ^{40}K in pine and birch roots is more effective than in other components of the tree.
6. It has been determined that due to the influence of plant roots in the tree under–crown zone ^{137}Cs migrates into deeper soil layers and at present it

reaches the 30 cm depth. In open localities not influenced by trees, ^{137}Cs migrates slower and does not exceed the 15–20 cm depth.

7. It has been found that the natural origin radionuclide ^{40}K competes with the artificial origin radionuclide ^{137}Cs . With the increase in the ^{40}K amount in soil, the ^{137}Cs penetration into segments of pines and birches decreases.
8. It has been established that the ^{137}Cs migration in the under-crown zone depends on the direction of prevailing winds and the tree crown. The ^{137}Cs specific activity in soil under foliage of birches is higher in the first and third zones. The ^{137}Cs specific activity in soil under the pine crown decreases with the increase in the distance from the tree trunk.
9. By comparing the experimental and theoretical models it has been determined that according to the theoretical model radionuclides reach only the 15 cm soil depth during 25 years, while in the experimental model radionuclide amounts are detected at the 25–30 cm soil depth. In the computer RSP model the radionuclide transfer in the system „soil – tree“ is evaluated according to the soil contamination in that region, and in the experimental model – according to the radionuclide amounts accumulated in tree components. Therefore, in the evaluation of former soil contamination in the zone of the tree influence, it is advisable to use the experimental model, which evaluates the radionuclide migration in the system “soil–tree” according to the specific local conditions.

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Rimantas Beinaravičius was born in Alytus district on 27 June, 1974. He finished Alytus secondary school No 10. In 1992, he entered the Lithuanian Agriculture University and in 1997 graduated from the University taking a degree of agriculturist. In 1997, R. Beinaravičius entered Vilnius Gediminas Technical University and got a diploma of the environment protection engineer. In 2001 he got a master's degree in Environment Engineering at the department of Environment Engineering of Vilnius Gediminas Technical University. In 1997–2001, he worked at the department of Environment Protection. In 2001–2005 Rimantas Beinaravičius was a Ph. D. student at Vilnius Gediminas Technical University. At present he is a research assistant at the Environment protection department of Vilnius Gediminas Technical University.

DIRVOŽEMIO ILGALAIKĖS UŽTARŠOS RADIONUKLIDAIŠ KAITOS TYRIMAS IR PROGNOZĖ PAGAL JŲ KAUPIMĄSI MEDŽIŲ SEGMENTUOSE

Problema

Žmonijos vystymasis neatskiriama susijęs su vis aktyvesniu jos poveikiu gamtai. Pastariesiems dešimtmečiams būdinga tai, kad dėl mokslo ir technikos pažangos žmogaus galimybės paveikti gamtą pradėjo gerokai viršyti jo sugebėjimą suprasti, įvertinti ir numatyti šios veiklos pasekmes, gana dažnai netikėtas ir nepageidautinas. Plėtojant branduolines technologijas, be kitų, iškilo ir aplinkos taršos radioaktyviosiomis medžiagomis problema. Jos pasekmės juntamos daugelį metų, o į aplinką patekę radionuklidai dalyvauja apykaitos tarp įvairių gamtinių terpių procesuose, sklinda dideliais atstumais, prasiskverbia į biologinius objektus ir kaupiasi juose.

Anksčiau, ypač po Černobylio atominės elektrinės (AE) katastrofos ir dabar daugiausia dėmesio tiek pasaulyje, tiek Lietuvoje buvo skiriama radioaktyviųjų medžiagų savitojo aktyvumo aplinkoje tyrimams. Tačiau dar daug problemų įvertinant jų biologinį pavojingumą, kaupimąsi ir migraciją bei pasišalinimą aplinkoje iš atskirų aplinkos objektų, o taip pat prognozuojant šiuos procesus.

Iš atmosferos radioaktyviosios medžiagos pasišalina su dulkėmis, gali būti išplautos su krituliais bei mažėja radioaktyviojo skilimo metu. Nusėdusius ant žemės radionuklidus sugeria dirva ir augmenija.

Temos aktualumas

Praėjus ilgesniam laikui po globalinių iškritų bei užtaršos po Černobylio AE katastrofos Lietuvos dirvožemiai labiausiai užteršti ^{137}Cs ir ^{90}Sr .

Šiame darbe įvertintas ^{137}Cs kaupimasis bei vertikalioji ir horizontalioji migracijos dirvožemyje. Nustatytas dirbtinės kilmės radionuklido ^{137}Cs savitasis aktyvumas medžių segmentuose, įvertinti pernašos koeficientai iš dirvožemio į įvairias sumedėjusio augalo dalis ir palyginti su natūralios kilmės radionuklido ^{40}K pernaša. Radionuklidų kaupimasis tiek dirvožemyje, tiek augaluose, išsiplovimas iš aplinkos, radioaktyvusis skilimas trunka ilgus metus, todėl tikslinga parinkti tinkamus metodus ir vertinti ilgalaikės taršos kaitos tendencijas. Į aplinką patekę radionuklidai kaupiami žemės augalinėje dangoje ir viršutiniame dirvos sluoksnyje. Jų kaupimas augaluose vyksta tiesiogiai iš atmosferos per jų antžemines dalis, o nuo lapų, šakų ir šakelių, bei šaknų paviršiaus, radionuklidai patenka į augalų audinius ir įsijungia į biologinę medžiagų apykaitą. Šitie procesai nėra pakankamai įvertinti, nors tai būdinga tiek biologiniu tiek aplinkosauginiu požiūriu. Įvertinus radionuklidų patekimą į medžius per jų antžeminę dalį ir per šaknis, galima modeliuoti ir prognozuoti radionuklidų kaupimąsi ir pasiskirstymą medyje, bei spręsti atvirkščiąją uždavinį – pagal radionuklidų savitąjį aktyvumą medienos rievėje atitinkančiais metais nustatyti jų turinį aktyvumą, bet kuriame dirvožemio gylyje.

Darbo tikslai:

Nustatyti dirbtinės kilmės radionuklido ^{137}Cs sandaupos dirvožemyje ir medyje, surasti pernašos koeficientus iš dirvožemio į įvairias sumedėjusių augalų dalis. Prognozuoti dirvožemio ilgalaikės užtaršos radionuklidais kaitą pagal jų sandaupą medžių dalyse.

Sudaryti radionuklidų migracijos modelį sistemoje “dirvožemis–medis”.

Darbo uždaviniai:

- Pritaikyti bandinių paėmimo, jų paruošimo radiometriniais tyrimams metodus ir įgyvendinti tam skirtą įrangą.
- Įsisavinti ir pritaikyti ^{137}Cs savitojo aktyvumo medienoje nustatymo metodiką.
- Nustatyti radionuklidų savitųjų aktyvumų medžių rievėse priklausomybę nuo užtaršos tankio įvairiuose dirvožemio gyliuose, dirvožemio tipo, cheminės sudėties, kritulių kiekio ir kitų faktorių.
- Nustatyti ^{137}Cs savitojo aktyvumo pasiskirstymą vertikaliame dirvožemio profilyje ir medžio segmentuose.
- Radionuklidų turinio aktyvumo pasiskirstymą dirvožemyje, nustatytą “medžio rėvių” metodu, patikslinti modeliuojant jų migraciją sistemoje „dirvožemis–medis”.

Darbo mokslinis naujumas

- Įvertintas radionuklidų patekimas į medį ne tik per išorinę, antžeminę jų dalį, bet ir per šaknis. Pagal tyrimų rezultatus galima nustatyti radionuklidų kaupimąsi medžiuose ir prognozuoti jonizuojančios spinduliuotės sugertąją dozę, kuria atskirais laikotarpiais buvo švitinami medžiai ne tik iš išorės, bet ir jų segmentuose.
- Pagal radionuklidų susikaupimą medžių rievėse modeliuojama ir prognozuojama buvusi dirvožemio užtarša atskirais metais ir nustatomas radioaktyviųjų iškritų paviršinis tankis.
- Nustatytas natūraliosios ir dirbtinės kilmės radionuklidų kaupimasis dirvožemyje medžių įtakos zonoje.
- Sukurtas modelis kuriuo galima įvertinti radionuklidų sklaidą dirvožemyje po medžių laja ir įvertinti pušies (*Pinus sylvestris L.*) bei beržo (*Betula pendula L.*) savybę kaupti radionuklidus.
- Patobulintas medžio rėvių atskyrimo metodas, naudojant kaltus–skeltuvus.

Praktinė darbo reikšmė

Pagal gautus rezultatus galima įvertinti įvairiais užtaršos laikotarpiais sugertas apšvitos dozes tiriamojo regiono sumedėjusiuose augaluose. Remianti darbo

rezultatais galima nustatyti radionuklidų apykaitą sistemoje dirvožemis–medis. Galima įvertinant šios apykaitos pertrūkį ir radionuklidų pasiskirstymą, kurie atsiranda dėl žmogaus veiklos medieną naudojant statybai ir baldų gamybai. Duomenys apie radionuklidų kaupimąsi įvairiuose medžiuose gali būti naudingi nagrinėjant medžių prieaugį ir įvairių medžių ligų plitimą. Be to, pagal darbo rezultatus ateityje galima bus įvertinti žmogaus apšvitą naudojant medieną buitinėse ir gamybinėse patalpose. Šis darbas reikšmingas, ir tuo, kad suradus pernašos koeficientus iš įvairių dirvožemių tipų į sumedėjusius augalus, bus galima įvertinti bendrą Lietuvos arba jos regionų miškų sistemos sukauptą dirbtinės kilmės radionuklido ^{137}Cs kiekį.

Darbo aprobavimas

Disertacijos rezultatai buvo aptariami keturiose tarptautinėse ir šešiose respublikinėse mokslinėse konferencijose. Disertacijos tema paskelbtos 2 publikacijos recenzuojamuose užsienio periodiniuose leidiniuose (vienas – ISI sistemos žurnale), 3 publikacijos recenzuojamuose periodiniuose leidiniuose Lietuvoje, 1 publikacija tarptautinių konferencijų medžiagoje ir 7 publikacijos respublikinių konferencijų medžiagoje, pateikta 1 paraiška išradimui gauti.

Apimtis ir struktūra

Disertaciją sudaro įvadas, 4 pagrindiniai skyriai, darbo išvados, 105 literatūros šaltiniai ir 13 publikacijų disertacijos tema sąrašai. Iš viso: 132 puslapiai teksto, 87 paveikslai ir 12 lentelių.

Bendrosios išvados

1. Dirbtinės kilmės radionuklidas ^{137}Cs į aplinką daugiausiai pateko per du užtaršos laikotarpius: branduolinio ginklo bandymų metu (1945–1980 m.) ir 1986 m., po ČAE katastrofos. Žemės paviršiuje susiformavo ^{137}Cs užtaršos “dėmės”. Vienos didžiausių Lietuvoje ^{137}Cs užtaršos zonų nustatytos Lietuvos vakarinėje dalyje, Klaipėdos regione ir pietinėje dalyje, netoli Alytaus.
2. Įsisavinta medžių segmentų (šaknų, spyglių, lapų, kamieno) bandinių paėmimo, jų paruošimo radiometriniais tyrimams ir tyrimo metodika, sukurta ir įgyvendinta tam skirta įranga.
3. Pagal radionuklidų sancaupą atskiruose medžio segmentuose, sukurta ir pritaikyta praktiniam naudojimui radionuklidų sklaidos sistemoje dirvožemis–medis eksperimentinis modelis. Sukurto modelio pagalba galima nustatyti radionuklidų sklaidą dirvožemyje po medžių laja ir įvertinti pušies ir beržo savybę kaupti radionuklidus. Naudojantis eksperimentiniu modeliu taip pat galima atkurti ir prognozuoti buvusią dirvožemio užtaršą.
4. Pastebėta dviejų tipų ^{137}Cs savitojo aktyvumo padidėjimo pušyje ir berže tendencija. Nežymus ^{137}Cs savitojo aktyvumo padidėjimas augančio

medžio medienoje, šiam radionuklidui prasiskverbus į jį iš spyglių ir žievės 1955–1980 m. bei 1986 m. ir žymesnis padidėjimas, maždaug po 10 metų po užtaršos, radioizotopams į medį patekus per jo šaknis.

5. Pušies spygliuose ir žievėje radioizotopų savitasis aktyvumas daugiau negu eile didesnis negu medienoje, nes lemia ne tik pernaša iš dirvos per šaknis, bet ir užtarša tiesiogiai iš oro. Pušies ir beržo šaknyse ^{137}Cs ir ^{40}K efektyviau kaupiasi negu kituose medžio sanduose.
6. Nustatyta, kad ^{137}Cs medžių polajinėje zonoje, dėl augalų šaknų įtakos, migruoja į gilesnius dirvožemio sluoksnius ir šiuo metu pasiekia 30 cm gylį. Atvirose medžių neįtakotose vietose, ^{137}Cs migruoja lėčiau ir nevirsėja 15–20 cm gylio.
7. Nustatyta, kad natūralios kilmės radionuklidas ^{40}K konkuruoja su dirbtinės kilmės radionuklidu ^{137}Cs . Didėjant dirvožemyje ^{40}K kiekiui, ^{137}Cs patekimas į pušų ir beržų segmentus mažėja.
8. Nustatyta, kad ^{137}Cs migracija polajinėje zonoje priklauso nuo vyraujančių vėjų krypties ir medžių lajos. Dirvožemyje po beržų lajomis ^{137}Cs savitasis aktyvumas yra didesnis 1 ir 3 zonose. Dirvožemyje po pušų lajomis ^{137}Cs savitasis aktyvumas mažėja tolstant nuo medžio kamieno.
9. Lyginant eksperimentinį ir teorinį modelius nustatyta, kad pagal teorinį modelį radionuklidai per 25 m. pasiekia tik iki 15 cm dirvožemio gylio, o eksperimentiniame modelyje radionuklidų kiekiai aptinkami 25–30 cm dirvožemio gylyje. Kompiuteriniu RSP modeliu radionuklidų pernaša sistemoje „dirvožemis – medis“ vertinama pagal dirvožemio užtaršą tame regione, o eksperimentiniame modelyje – pagal medžių sanduose sukauptų radionuklidų kiekius. Vertinant buvusią dirvožemio užtaršą medžių įtakos zonoje, rekomenduojama naudoti eksperimentinį modelį kuris tiksliau išreiškia radionuklidų migraciją sistemoje dirvožemis – medis pagal konkrečias vietos sąlygas.

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**INVESTIGATION AND FORECAST OF VARIATION OF
LONG-TERM SOIL CONTAMINATION WITH
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Summary of Doctoral Dissertation

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Vilnius  2005

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