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# Peculiarities of $^{137}Cs$ activity distribution in the aquatic solution – solid phase – plant system

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The ability of the plant *Lepidium sativum* L. (seeds, roots and aboveground part) to accumulate $^{137}Cs$ from aquatic solution during the entire growth period was investigated under model experimental conditions. Analysis of the redistribution of this radionuclide in the aquatic solution – solid phase – plant model system using as a nutrition medium one-component ($^{137}Cs$) or two-component ($^{137}Cs$ in combination with sodium nitrate) aquatic solutions was carried out. $^{137}Cs$ transfer from the roots to the aboveground part was determined. Evaluation of suitability of *Lepidium sativum* L. as a toxicity bio-test of the effect of $^{137}Cs$ and of $^{137}Cs$ in combination with sodium nitrate was made as well.

**Key words:** $^{137}Cs$ accumulation, aboveground part, roots, seeds, sodium nitrate, test-organism *Lepidium sativum* L.

## INTRODUCTION

In terrestrial ecosystems, plants are a relevant chain in radionuclide spreading processes. The radionuclide fallout from the atmosphere is first of all held up by tree crowns (from 40 to 90%) and other plants (Тихомиров, Щеглов, 1997). Part of radionuclides deposited on trees and plants are blown off by the wind and the others are washed down by wet precipitation. Consequently, radionuclide redistribution between plants and surface litter takes place. Because of atmospheric fallout and litter mineralization, radionuclides reach the soil rooting zone. Radionuclide accumulation in the soil depends on their distribution between two main soil phases, *i.e.* solid and liquid (soil solution), where processes of adsorption–desorption as well as dissolution and coagulation take place (Colston, Robinson, 1995; Dumant, Staunton 1999; Staunton, Levacic, 1999). This distribution is conditioned by various factors such as physico-chemical features of the liquid and solid phases and radionuclides and the amount of chemical analogues in solid and liquid phases and plants. Referring to the classification of chemical elements and radioisotopes by the famous Russian scientists Timofeev-Resovskyj and Timofeeva-Resovskaya (Тимофеева-Ресовская, 1963), $^{137}Cs$ is attributed to the radionuclides of which more than 70% are accumulated in soil.

Transfer of radionuclides from soil to plants highly depends on radionuclide mobility in soil solid and liquid phases. Chemical elements according to their mobility in soil are divided into immobile, slightly mobile, mobile and strongly mobile (Nedveckaitë, 2004). After the Chernobyl NPP accident, among investigations in the field of determination of regularities of radionuclide migration in soil as well as their accumulation in the soil – soil solution – plant root system, studies of $^{137}Cs$ (slightly mobile), $^{90}Sr$ (mobile) and some of immobile or slightly mobile transuranics were prevailing. The maximum $^{137}Cs$ flux from soil to plants was observed in 1987–1989 (Grodsinsky, 2001). At present, this flux is about 10 times lower. Such phenomenon in soil was called “ageing”, but the reasons of the process are not yet sufficiently known. Investigations show that the highest amount of Chernobyl-derived $^{137}Cs$ is accumulated in a 10–15 cm soil layer. Stimulation of natural remediation processes in territories contaminated with radionuclides is achieved through radionuclide redistribution among the components of the ecosystem and their introduction into the biogeochemical cycles of the ecosystem. When radionuclides get into soil through the soil liquid, they join the processes of biological circulation in the soil – plant root system. Radionuclide accumulation in plants from soil via the root system is a rather complex and insufficiently investigated process. It is influenced by radionuclide physical and chemical features as well as by soil type, its pH, sorption capacity and organic matter amount and the plant biological peculiarities (Алексахин, 1991; Avery, 1996).

The processes of radionuclide translocation (radionuclide transfer from one part of a plant to another, also from the root system to plant aboveground part) are not well studied (Fortunati et al., 2004;

Tyson et al., 1999). The basic factors having an effect on this process are the physiological peculiarities and growth stage of a plant. Dependence of translocation of various radionuclides in a plant upon its growth stage is not yet accurately determined (Nedveckaitë, 2004). For example, investigation results of $^{137}$Cs and $^{90}$Sr transfer from soil to plant roots and their translocation in the plant are scarce and often contradictory.

Investigations of radionuclide accumulation in abiotic and biotic components of an ecosystem and the processes of radionuclide transfer from one component to another, as well as the effect of various factors on these processes are of great importance for the spreading of contaminants in an ecosystem and autorehabilitation of contaminated territories.

The aim of this study was to investigate under experimental conditions $^{137}$Cs accumulation in different parts (seeds, roots, aboveground part) of the plant *Lepidium sativum* L. from aquatic solution throughout the growth period; to determine redistribution of this radionuclide in the aquatic solution – solid phase – plant model system from one-component ($^{137}$Cs) and bi-component ($^{137}$Cs and sodium nitrate) media; to determine $^{137}$Cs transfer from roots to the aboveground part depending on the plant growth stage; to evaluate *Lepidium sativum* L. as a bio-test for toxicity assessment, usability for the study of its sensitivity to $^{137}$Cs and to $^{137}$Cs in combination with sodium nitrate.

## MATERIALS AND METHODS

$^{137}$Cs biological accumulation, by evaluating the effect of sodium nitrate and solution pH on this process, was studied using the plant test-organism *Lepidium sativum* L. which is widely applied in toxicological studies (Gong et al, 1999; Ì àãî í å, 1989; Wang, 1992). Seeds of this plant germinate within two days and sprouts develop within seven days, therefore it is possible to study $^{137}$Cs accumulation throughout the entire plant growth period, *i.e.* from seeds to developed sprouts. Methodically, it is impossible in model laboratory or field experiments to use soil of any composition for investigation of $^{137}$Cs influence on *Lepidium sativum* L. root growth. By preliminary investigations, a similarity of $^{137}$Cs accumulation in filter paper and sand was obtained. The $^{137}$Cs accumulation coefficient in filter paper was like that in sand presented in Марчюлёнене и др., 1992. The above statements directed us at applying filter paper instead of soil in the aquatic solution – solid phase – plant system. This alternative is valid especially bearing into consideration that in terrestrial ecosystems $^{137}$Cs is mainly accumulated not from soil but from soil solutions. When $^{137}$Cs is accumulated by plant roots from soil solution, the competitive relations between soil and plant roots take place. Regarding soil granulometric composition and the amount of organic substances, large-scale variations of the $^{137}$Cs accumulation coefficient values were obtained (Марчюлёнене и др., 1992).

Experiments of the first series, i.e. experiments for examination of $^{137}$Cs accumulation in *Lepidium sativum* L. seeds, roots and solid phase and the distribution of this radionuclide in the aquatic solution – solid phase – plant model system as well as $^{137}$Cs effect on root growth in one-component ($^{137}$Cs) and bi-component ($^{137}$Cs together with sodium nitrate) media were performed in Petri dishes (three repetitions). Dishes with 10 ml of aquatic solution and 25 seeds evenly distributed on filter paper were placed in a thermostat (in the dark) at 24 ± 1 °C for two days. Lake water (pH 7.5) was used for preparation of aquatic $^{137}$Cs and sodium nitrate solutions. $^{137}$Cs activity concentration values in aquatic medium (pH 7.5) were 0.4, 4.0, 40 and 440 kBq/l. $^{137}$Cs activity concentration values in the aquatic solution with sodium nitrate were 0.2, 2.0, 20 and 200 kBq/l, but the pH values of these aquatic solutions were 7.34, 7.40, 7,89 and 8.01, respectively. Sodium nitrate concentration values in the aquatic solution were 0.01, 0.12, 1.19 and 11.9 g/l. Investigating the pH impact on $^{137}$Cs accumulation in *Lepidium sativum* L. roots, the pH values were changed in the following rank: 4.03, 3.00, 2.02 and 1.12.

Experiments of the second series on $^{137}$Cs accumulation from a one-component aquatic medium ($^{137}$Cs alone) in *Lepidium sativum* L. roots, aboveground part and solid phase and radionuclide redistribution among these components were carried out. For this purpose plastic boxes with a lid were used.

A thin glass slab covered with filter paper and 470 g (about 160 units) of seeds on it was placed in a box in 65 ml of aquatic $^{137}$Cs solution. Seeds were germinated for one day in the dark and the sprouts were grown for six days in the permanent light at a temperature of 23 ± 1 °C. In this series of experiments, $^{137}$Cs activity concentration in the solution was 40 kBq/l and the solution pH was 7.5.

A one-component model system was prepared using 0.1 ml $^{137}$Cs aquatic hydrochloric acid solution diluted $10^5$–$10^8$ times; therefore the $Cl^-$ ion had no influence on the plant seed germination and plant development. The bi-component model system was obtained from $^{137}$Cs aquatic nitric acid solution, neutralizing it to a pH close to lake water pH. Neutralization was conducted by using a sodium alkaline solution, because the influence of sodium ions on plant development is less in comparison with ammonium or potassium ions. Strong acid and strong alkaline in the aquatic solution dissociate into ions as well as salts of strong acids and bases decompose into ions:

$$Na^+ + OH^- + H^+ + NO_3^- \rightarrow Na^+ + NO_3^- + H_2O.$$

Model systems with the $^{137}$Cs activity concentrations of an order of 10 and 100 kBq/l contained a

Table 1. **$^{137}$Cs accumulation coefficient ($A_C$) in *Lepidium sativum* L. roots and in solid phase depending on this radionuclide activity concentration in aquatic solution after two days**

| Solution pH | Initial $^{137}$Cs activity in aquatic solution, kBq/l | $^{137}$Cs $A_C$ in solid phase | $^{137}$Cs $A_C$ in roots | Root length, % |
|---|---|---|---|---|
| 7.50 | 0.40 ± 0.03 | 36 ± 7 | 53 ± 5 | 110.8 ± 2.6 |
| 7.50 | 4.0 ± 0.3 | 32 ± 3 | 53 ± 5 | 111.1 ± 2.5 |
| 7.50 | 40 ± 3 | 30 ± 3 | 50 ± 5 | 110.7 ± 2.5 |
| 7.50 | 440 ± 30 | 30 ± 3 | 54 ± 5 | 111.9 ± 2.3 |

Table 2. **$^{137}$Cs accumulation coefficient ($A_C$) in *Lepidium sativum* L. roots and in solid phase depending on $NaNO_3$ concentration in aquatic solution after two days**

| Solution pH | $NaNO_3$ concentration in solution, g/l | Initial $^{137}$Cs activity in aquatic solution, kBq/l | $^{137}$Cs $A_C$ in solid phase | $^{137}$Cs $A_C$ in roots | Root length, % |
|---|---|---|---|---|---|
| 7.34 | 0.01 | 0.20 ± 0.02 | 8.7 ± 0.9 | 17.9 ± 1.8 | 87.1 ± 2.9 |
| 7.40 | 0.12 | 2.0 ± 0.1 | 23 ± 2 | 33 ± 3 | 81.2 ± 2.3 |
| 7.89 | 1.19 | 20 ± 1 | 12.1 ± 1.2 | 28 ± 3 | 62.9 ± 2.7 |
| 8.01 | 11.9 | 200 ± 10 | 4.4 ± 0.4 | 5.5 ± 0.5 (seeds did not germinate) | 0 |

Table 3. **$^{137}$Cs accumulation coefficient ($A_C$) in *Lepidium sativum* L. roots, depending on solution pH (after two days)**

| Solution pH | $^{137}$Cs $A_C$ in roots | Root length, % |
|---|---|---|
| 7.50 | 50 ± 5 | 110.8 ± 2.6 |
| 4.03 | 35 ± 3 | 75.5 ± 5.7 |
| 3.00 | 42 ± 4 | 73.1 ± 4.9 |
| 2.02 | 4.2 ± 0.4 (seeds did not germinate) | 0 |
| 1.12 | 3.2 ± 0.3 (seeds did not germinate) | 0 |

larger volume of $^{137}$Cs aquatic nitric acid solution. To neutralize the systems, a larger volume of sodium alkaline solution was needed, therefore rather high sodium nitrate or $NO_3^-$ ion concentrations in this type bi-component solution were obtained. $NaNO_3$ and $NO_3^-$ concentrations (g/l) in different variants were the following: 1) 0.01 and 0.01; 2) 0.12 and 0.09; 3) 1.19 and 0.87; 4) 11.9 and 8.68. In 2–4 variants of the study model ($^{137}$Cs + sodium nitrate) systems, $NO_3^-$ ion concentration from 10 to 1000 times exceeded that of the quality standard in groundwater (EU Directive 98/83/EC, 1998). In the first variant, the nitrate concentration (0.01 g/l) was in line with the nitrate concentration (0–0.01 g/l), characteristic of aquatic media unpolluted by anthropogenic factors (Neemann, 2004). Our experimental series with a nitrate concentration of 0.09 g/l corresponded to water polluted with nitrates from agricultural sources (EU Directive 91/676/EEC, 1991). The highest sodium nitrate concentrations (1.19 and 11.9 g/l) in our investigations were chosen to determine *Lepidium sativum* L. tolerance limits to this chemical compound.

$^{137}$Cs activity concentration in aquatic solution, solid phase and in plant biomass was evaluated by γ-spectrometric analysis. Measurements of $^{137}$Cs activity of aquatic solution were performed in small-volume dishes of standard geometry (depth 40 mm and diameter 16 mm) to which 3 ml of the solution were poured in. For γ-spectrometric measurements, samples of solid phase and the plant were dried at room temperature, pulverized and placed into the mentioned dishes of standard geometry. $^{137}$Cs measurements were carried out using a γ-spectrometer with a well-type high purity germanium (HPGe) detector. At the statistic error level of 1%, measurement uncertainty did not exceed 6% (Gudelis et al., 2000).

For comparison of $^{137}$Cs accumulation in *Lepidium sativum* L. seeds, roots and aboveground part and in the solid phase as well as radionuclide accumulation in the roots from aquatic solution with different ion composition, the $^{137}$Cs accumulation coefficient ($A_C$) was calculated. $A_C$ was expressed as a ratio of radionuclide activity concentration in the organism or in the solid phase (Bq/kg dry weight) with that in the aquatic solution (Bq/l). The accumulation coefficient is a biological characteristic indicating the ability of an organism or its separate organs to accumulate radionuclides from various environmental and model solutions; it is independent of the radionuclide activity in the solution under the same conditions (Поликарпов, 1964).

## RESULTS AND DISCUSSION

According to the experimental results (nutrition medium – water with $^{137}$Cs without sodium nitrate), $A_C$

of $^{137}$Cs in *Lepidium sativum* L. roots after two days ranged from 50 to 54, in the solid phase from 30 to 36, independently of the $^{137}$Cs activity concentration in the solution (Table 1).

Comparison of $^{137}$Cs $A_C$ values in *Lepidium sativum* L. seeds, roots and aboveground part demonstrated that in seeds after 1 day it was 15.1, and after 7 days in roots it was 3000, in the aboveground part reaching – 880. The accumulation coefficient $A_C$ of $^{137}$Cs in the solid phase was equal to 250.

Investigations on the effect of $^{137}$Cs on *Lepidium sativum* L. root growth showed that the root growth was stimulated (11–12%) statistically reliably compared to control, irrespective of $^{137}$Cs activity concentration studied.

Our previous study has shown that $^{137}$Cs accumulation in plant cells takes place both because of adsorption on the cell wall (it accumulates up to 85% of this radionuclide) and active $^{137}$Cs transport through the external and internal cytoplasm membranes into interior cell components where about 20% of this radionuclide is transferred from the cell wall (Марчюлёнене и др., 1992). Cation accumulation in the plant cells is conditioned by cation accumulation in the cell wall – protoplasm ion-exchangeable complex. This complex controls cation transfer into interior cell compartments and depends on this complex biological activity, which can be influenced by chemical pollution. *Lepidium sativum* L. as a test-organism is widely used for evaluating the toxicity of effluents of different chemical composition and different pH or dump filtrates and other sites contaminated with chemical substances. We studied the effects of different sodium nitrate (it can enter water basins with various effluents) and aquatic solution pH on $^{137}$Cs accumulation in *Lepidium sativum* L. roots. $^{137}$Cs as a chemical analogue of potassium participates in plant metabolic processes; therefore accumulation of this radionuclide in plants depends on their cell functional state which can be damaged by chemical pollution.

In experimental series where a nutrient solution contained $^{137}$Cs and sodium nitrate (0.01–1.19 g/l), the $A_C$ of $^{137}$Cs in the plant roots after two days ranged from 17.9 to 33 and in the solid phase from 8.7 to 23 (Table 2). In aquatic $^{137}$Cs solution in which sodium nitrate concentration was 11.9 g/l, plant seeds did not germinate at all; the $A_C$ of $^{137}$Cs value in seeds was 5 and in the solid phase only 4. The obtained results suggest that a decrease (on average three times) in *Lepidium sativum* L. root and the solid phase ability to accumulate $^{137}$Cs are caused by sodium nitrate presence together with $^{137}$Cs in the aquatic solution. $^{137}$Cs accumulation in the solid phase decreased even seven times when sodium nitrate concentration in aquatic solution was11.9 g/l and seeds did not germinate.

Analysis of results has shown that $^{137}$Cs in combination with sodium nitrate at a concentration of 0.01, 0.11 and 1.19 g/l in aquatic solution suppressed root growth statistically reliably (by 13 to 37%) compared to control.

Investigation of the $A_C$ of $^{137}$Cs in *Lepidium sativum* L. roots depending on aquatic solution pH showed that the change in solution pH values (7.50, 4.03 and 3.00), had almost no influence after two days on the $A_C$ values, because they were 50, 35 and 42, respectively (Table 3). The decrease of solution pH from 7.50 to 3.00 had an insignificant influence on the plant root ability to accumulate $^{137}$Cs. However, when the aquatic solution became more acidic and its pH was 2.00 and 1.12, *Lepidium sativum* L. seeds did not germinate. The $A_C$ values of $^{137}$Cs in seeds were 4.2 and 3.2, respectively, *i.e.* they were significantly lower than in seeds after one day growth when the solution pH was 7.50.

The summarized data allow to state that the $^{137}$Cs accumulation coefficient in *Lepidium sativum* L. roots was five times higher than in the aboveground part. The $A_C$ of this radionuclide in the solid phase was 12 times lower than in the roots and 3.5 times lower than in the aboveground part. In the experiments when seeds were placed in an aquatic $^{137}$Cs solution, rooth growth stimulation was determined. Presence of sodium nitrate at the concentrations from 0.01to 1.19 g/l reduced $^{137}$Cs accumulation in *Lepidium sativum* L. roots (on average two times), in the solid phase (3 times), and roots were shorter by 13–37%, respectively.

Under the effect of sodium nitrate, $^{137}$Cs accumulation in the solid phase was reduced evidently because of changes in the physico-chemical processes taking place between aquatic solution and solid phase. The decrease of $^{137}$Cs accumulation in the plant roots could be induced by the worsening of the functional state of root cells.

The aquatic medium pH values in a rather wide range (from 7.5 to 3.0) practically did not influence the ability of this plant to accumulate $^{137}$Cs. But in the aquatic medium with pH 4.03 and 3.00, root length in comparison with control became shorter by 24% and 27%, respectively. An insignificant change of $^{137}$Cs accumulation in the plant roots in comparison with that at low pH values was observed, most probably because of an increase in cell membrane permeability and an enhanced radionuclide transport into inner cell compartments (Марчюлёнене и др., 1992).

In the first experimental series, $^{137}$Cs activity distribution in the aquatic solution – solid phase – plant biomass system was studied depending on the mass of these components at the root growth stage. It was determined that after two days in the aquatic solution whose mass constituted up to 85.5% there remained 15% of $^{137}$Cs activity (Fig. 1). The mass of the solid phase comprised 13.9%, and it absorbed 80% of $^{137}$Cs, while 5% of this radionuclide was ac-

cumulated in the plant *Lepidium sativum* L. (mass share came up only to 0.6%).

In the second experimental series, $^{137}$Cs distribution in the aquatic solution – solid phase – plant biomass system at the sprout development stage (7-day experiment) was analysed. The highest $^{137}$Cs percentage (49%) after two days was determined in the aquatic solution whose mass constituted up to 96.7% (Fig. 2). 43% of $^{137}$Cs activity was accumulated in the solid phase whose mass share was 2.7%. Plant roots and sprouts, whose biomass was respectively 0.2% and 0.4%, accumulated 4% of $^{137}$Cs activity. Hence, in both the first and second series of experiments $^{137}$Cs accumulation in plant biomass after two days differed insignificantly. However, $^{137}$Cs distribution among the study components after seven days changed distinctly (Figs. 1, 2).

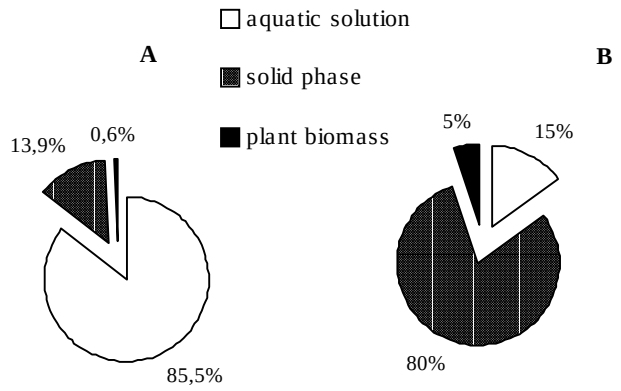


**Fig. 1.** Intercomponental distribution of mass (A) and $^{137}$Cs activity after two days (B) in the aquatic solution – solid phase – plant (*Lepidium sativum* L.) system at the root growth stage (day two of experiment)

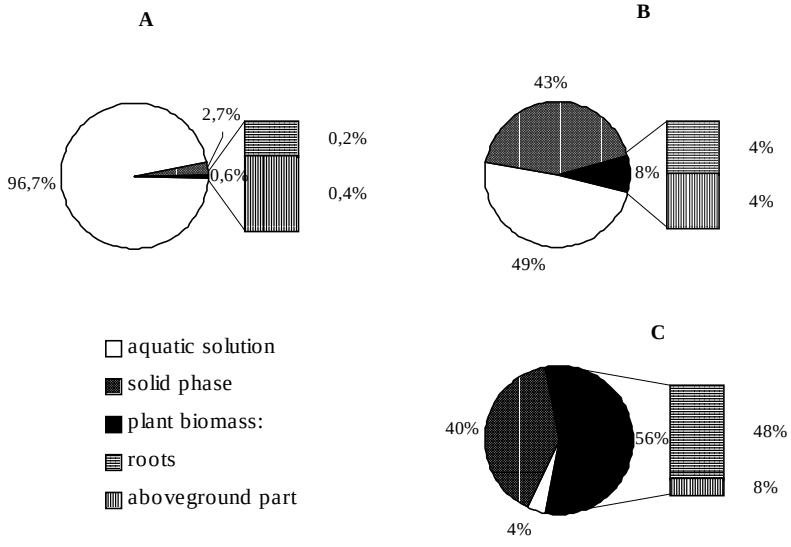


**Fig. 2.** Intercomponental distribution of mass (A) and $^{137}$Cs activity after two (B) and seven days (C) in the aquatic solution – solid phase – plant (*Lepidium sativum* L.) system at the sprout development stage (7 day experiment)

In the aquatic medium whose mass was 96.7% there remained only 4% of $^{137}$Cs (Fig. 2). From the aquatic medium to the solid phase (mass was 2.7%) were transferred 40% of $^{137}$Cs. The largest amount of $^{137}$Cs (56%) was determined in the plant biomass whose percentage share was only 0.6 %. In the plant biomass, $^{137}$Cs was distributed as follows: 46% in the roots and 8% in the aboveground part.

The dynamics of $^{137}$Cs distribution in the aquatic solution – solid phase – plant biomass system during the growth process of the plant *Lepidium sativum* L. showed a 49% decrease in $^{137}$Cs activity (Fig. 3) in the aquatic solution within the first two days, because 43% of the radionuclide was transferred to the solid phase. Within the 2–7-day period, $^{137}$Cs transfer from the aquatic solution to the solid phase changed insignificantly. In the plant root growing period (up to 2 days), radionuclide transfer from the aquatic solution to the plant roots increased from 5 to 8%, but when sprouts rose, within a 2–7-day period, $^{137}$Cs transfer from the aquatic solution to the plant increased from 8% to 56%. Analysis of $^{137}$Cs distribution dynamics in the roots – aboveground part system of the plant *Lepidium sativum* L. indicated not a very significant $^{137}$Cs transfer from the root system to the aboveground part, 3.6% and 8.0%, respectively, from the radionuclide amount accumulated in the whole plant during the growth process within a 2–7-day period (Fig. 4).

In a bi-component medium ($^{137}$Cs and sodium nitrate), increasing the sodium nitrate concentration from 0.12 to 11.9 g/l caused a reduction of $^{137}$Cs transfer from the aquatic solution to the plant roots and particularly to the solid phase. A decrease in $^{137}$Cs activity was determined from 5% to 2% in roots and from 74% to 35% in the solid phase. The percentage of this radionuclide activity in the aquatic solution was higher when sodium nitrate concentration rose from 0.12 to 11.9 g/l. The increase in sodium nitrate concentration changed $^{137}$Cs activity by 22 to 63% (Fig. 5). The obtained data show that nitrates released in the environment can influence $^{137}$Cs migration in the aquatic solution – solid phase – plant system.

To summarise the obtained data, it can be asserted that $^{137}$Cs transport from the aquatic solution to the solid phase was most intensive during the first two days (up to 43%), but within a 2–7-day period it changed insignificantly. The process of $^{137}$Cs transfer from the aquatic solution to the plant proceeded within the entire plant development period. A similar tendency was observer for $^{137}$Cs accumulation in summer wheat (*Triticum aestivum* L. Nan-

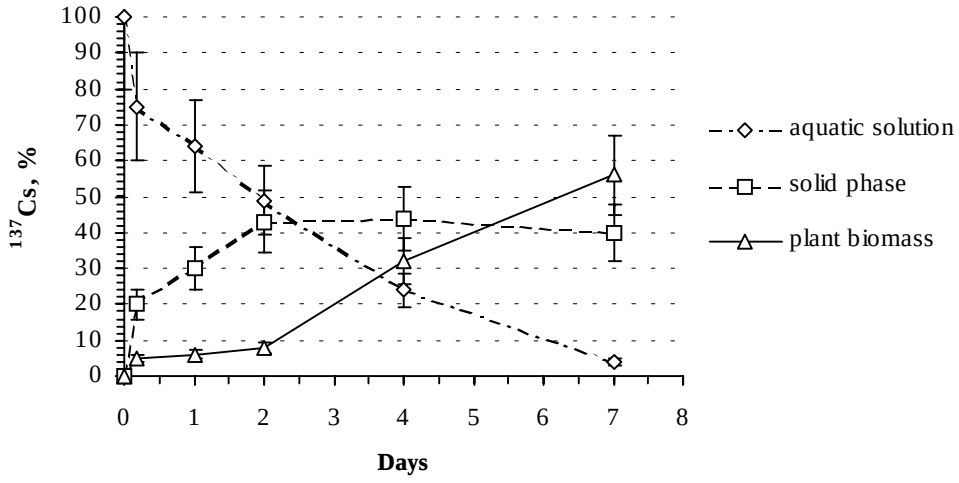


**Fig. 3.** Dynamics of $^{137}$Cs activity distribution in the aquatic solution – solid phase – plant system (during *Lepidium sativum* L. growth process)

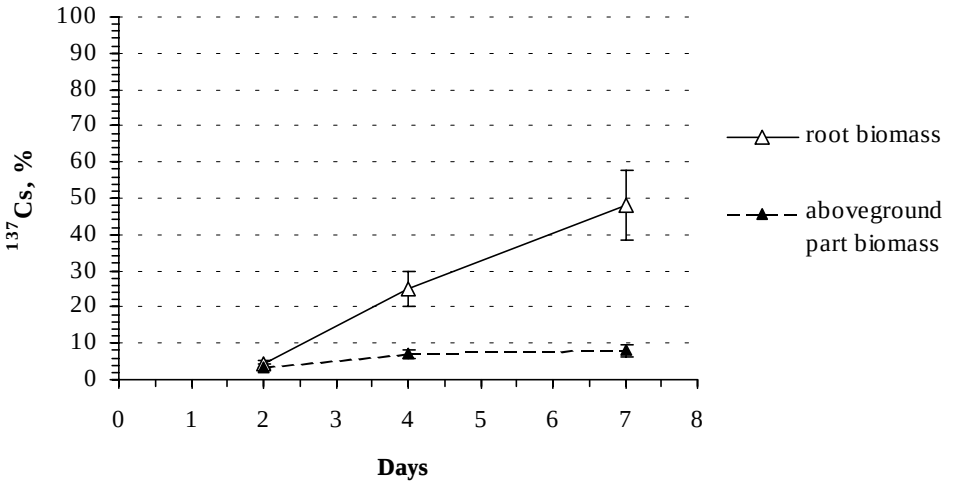


**Fig. 4.** Dynamics of $^{137}$Cs activity distribution in the roots – aboveground part system (during *Lepidium sativum* L. growth process)

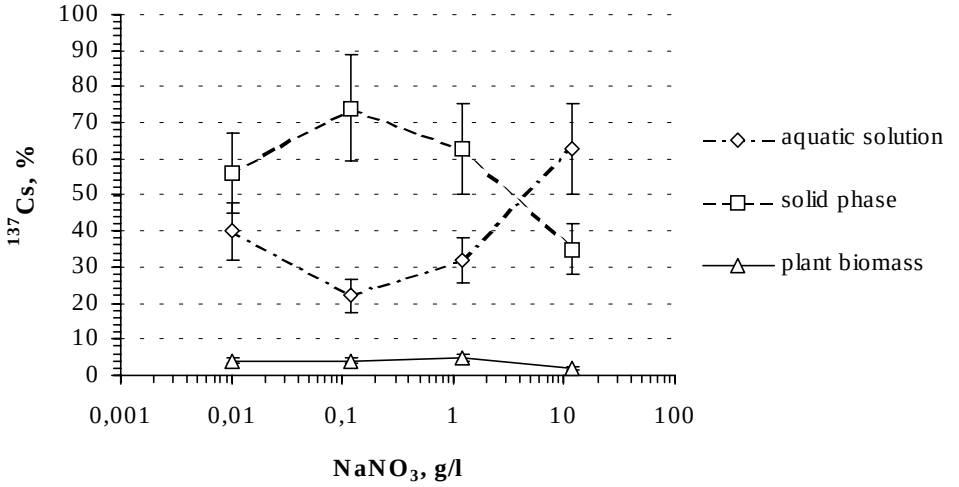


**Fig. 5.** $^{137}$Cs activity distribution in the aquatic solution – solid phase – plant (*Lepidium sativum* L.) system at different $NaNO_3$ concentrations

du). A gradual increase in the radionuclide activity in the summer wheat sprouts was determined during a 26-day growth period (Lukðienë et al., 2004).

$^{137}$Cs transfer from the aquatic solution to the plant roots amounted to 5–8% within a stage of the plant root growth (two days). The most intensive $^{137}$Cs transfer from the aquatic solution to the plant (from 8 to 56%) took place in the period of 2–7 days. At this plant growth stage, the highest $^{137}$Cs activity share fell to the plant roots (48%). $^{137}$Cs transfer from roots to the aboveground part increased by 3.6–8% at the sprout growth stage. In the bi-component ($^{137}$Cs + sodium nitrate) aquatic solution, a rise of sodium nitrate concentration from 0.12 to 11.9 g/l induced the diminution of $^{137}$Cs transfer to the plant roots and the solid phase, respectively, from 5% to 2% and from 74% to 35% and an increase of this radionuclide protion in the aquatic solution from 22% to 63%. Data show that the intensity of $^{137}$Cs transfer from the aquatic solution to the plant depends on the plant growth stage. At the sprout development stage (2–7-day period), $^{137}$Cs transport from the aquatic solution to the plant is more intensive than

that at the stage of root growth (within the first two days). $^{137}$Cs transfer from the aquatic solution to the solid phase, on the contrary, is the most intensive within the first two days, while within the period of 2–7 days it changes insignificantly. Presence of sodium nitrate has a great influence on the $^{137}$Cs transfer process in the aquatic solution – solid phase – plant system.

## CONCLUSIONS

The $^{137}$Cs accumulation coefficient ($A_C$) in *Lepidium sativum* L. roots was 3.4 times higher in comparison with the aboveground part. $^{137}$Cs, irrespective of its tested activity (from 0.4 to 440 kBq), stimulated root growth (11–12%).

Sodium nitrate concentration of 0.01g/l (characteristic of the water media not influenced by anthropogenic sources) caused a three-time $A_C$ decrease and a shortening of root length by 13% as compared to control. An augmentation of sodium nitrate concentration to 1.19 g/l decreased $^{137}$Cs $A_C$ in roots 1.9 times and root length by 30% *versus* control. The obtained data show that *Lepidium sativum* L. is a rather sensitive biotest to evaluate the toxic effects of nitrates.

*Lepidium sativum* L. root ability to accumulate $^{137}$Cs from its aquatic solutions in which pH values were gradually decreased from 7.5 to 3.0 changed insignificantly, however, the root length decreased by 24% *versus* control.

The intensity of $^{137}$Cs transfer from the aquatic solution to the plant depended on the plant growth stage. At the sprout development stage (2–7 days), $^{137}$Cs transfer from the aquatic solution to the plant was more intensive than that at the root development stage (up to two days). Presence of sodium nitrate at a concentration of 0.01 to 1.19 g/l in the aquatic solution significantly changed $^{137}$Cs accumulation peculiarities. An increase of sodium nitrate concentration decreased $^{137}$Cs activity in plant roots and solid phase, while the highest $^{137}$Cs activity remained in the aquatic solution.

The obtained data show that nitrates released in the environment can influence $^{137}$Cs migration in the aquatic solution – solid phase – plant system.

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## $^{137}$CS AKTYVUMO PASISKIRSTYMO SISTEMOJE VANDENINIS TIRPALAS–KIETOJI FAZË–AUGALAS YPATUMAI

Santrauka

Eksperimentinëmis sàlygomis iðtirtas augalo *Lepidium sativum* L. (sëklø, ðaknø ir antþeminës dalies) sugebëjimas kaupti $^{137}$Cs ðio augalo augimo procese ið vandeninio tirpalo, ðio radionuklido persiskirstymas modelinëse sistemose vandeninis tirpalas–kietoji fazë–augalas vienkomponentëje (tik $^{137}$Cs) ir dvikomponentëje ($^{137}$Cs su natrio nitratu) terpëje, nustatyta $^{137}$Cs pernaða ið ðaknø á antþeminæ dalá bei ávertintas *Lepidium sativum* L., kaip toksiškumo vertinimo biotesto, jautrumas $^{137}$Cs ir šio radionuklido su natrio nitratu poveikiui. Nustatyta, kad augalo *Lepidium sativum* L. šaknyse $^{137}$Cs $A_C$ buvo 3,4 karto didesnis negu antþeminëje jo dalyje. $^{137}$Cs nepriklausomai nuo jo tirtø aktyvumo koncentracijø (nuo 0,4 iki 440 kBq/l) 11–12% stimuliavo ðaknø augimà. Esant natrio nitrato koncentracijai 0,001 g/l, kuri atitinka nitratø koncentracijos lygá antropogeniniø veiksniø nepaliestuose vandens baseinuose, $^{137}$Cs $A_C$ augalo ðaknyse sumaþëjo 3 kartus, o ðaknys sutrumpëjo 13% (palyginus su kontrole). Didëjant natrio nitrato koncentracijai iki 1,19 g/l $^{137}$Cs $A_C$ ðaknyse sumaþëjo 2 kartus, o ðaknys sutrumpëjo 30% (palyginus su kontrole). Esant natrio nitrato koncentracijai 11,9 g/l po 2 parø sëklos nesudygo. Gauti duomenys rodo, kad *Lepidium sativum* L. yra pakankamai jautrus biotestas, vertinant nitratø toksiná poveiká. Vandeniniame tirpale, kurio pH buvo nuo 7,5 iki 3,0, *Lepidium sativum* L. ðaknø sugebëjimas kaupti $^{137}$Cs maþai tekito, taèiau ðaknys sutrumpëjo 24% (palyginus su kontrole). $^{137}$Cs pernaðos ið vandeninio tirpalo á augalà intensyvumas priklauso nuo jo augimo stadijos. Augalo daigø augimo stadijoje (2–7 paros) $^{137}$Cs pernaða ið vandeninio tirpalo á augalà buvo intensyvesnë negu ðaknø augimo stadijoje (per pirmas 2 paras). Dël natrio nitrato poveikio $^{137}$Cs pernaša iš vandeninio tirpalo á augalà ryðkiai pasikeitë: $^{137}$Cs aktyvumas augalo ðaknyse, taip pat kietojoje fazëje, kintant natrio nitrato koncentracijai nuo 0,01 iki 1,19 g/l, sumaþëjo, o vandeniniame tirpale liko daugiau $^{137}$Cs. Gauti duomenys rodo, kad nitratai, patekæ á aplinkà, gali pakeisti $^{137}$Cs migracijà sistemoje vandeninis tirpalas–kietoji fazë–augalas.

**Raktaþodþiai**: $^{137}$Cs akumuliacija, antþeminë dalis, ðaknys, sëklos, natrio nitratas, testorganizmas *Lepidium sativum* L.