Peculiarities of absorption of radionuclides by perennial and annual plants from contaminated soils

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Introduction

Accidents at the Chernobyl and Fokushima nuclear power plants and the radionuclide contamination of the surrounding areas have raised questions: which of the products grown in these areas is safe for human health and when will the products grown in these areas no longer be dangerous to human health [1,2,3]. According to life expectancy, plants are divided into annuals (that perform their entire life cycle in a few months) and perennials (which absorb very little water in winter). Due to the different specifics of water intake, their phytoremediation properties are different.

Methodology

The content of radionuclides in the studied soils and plants was determined by gamma-spectrometric analysis. Measurements were performed with a high-purity germanium semiconductor (hPGe) detector and multi-channel analyzer (InSpeqtor-2000). Spectrometric measurement software ENIE-2000 and quantitative measurement software ISOCS / labSOCS were used to process the measurements.

To determine the absorption of Cs^{137} by perennial plant organs, fern and Spiraea japonica have been selected. Both samples have been taken from the small town of Anaseuli, where the "Radiation Ecology Laboratory" operated during the Soviet period, and currently, the area is spotted with radionuclide contamination [4,5].

Organs	Pure	Contaminated
Leaf	38	22
Stem	10	4,3
Root	24	27

Table-1a

Organs	Pure	Contaminated
Leaf	4920	8260
Stem	2160	1815
Root	1600	2540

Table-1b

As a result of the surface scan of the research area, 2 zones of low and high contamination have been selected. Soil samples taken from these zones detected Cs^{137} activity at 32 Bq / kg and 12000 Bq / kg, respectively. The data for C^{137} and K^{40} absorbed by the Spiraea japonica organs from these soils are given in Table 1.

Table 1a shows the concentration of Cs^{137} in plant organs from pure and contaminated areas, and Table 1b shows the concentration of K^{40} in the same areas.

One interesting phenomenon was observed: the activity of Cs^{137} (53 Bq / kg) in the leaf of the sample taken from the high contamination zone was lower than the activity of Cs^{137} (72 Bq / kg) in the leaf of the sample taken from the low contamination zone. This fact is explained in this paper by a multi-point distribution of contamination: although the activity of Cs^{137} in the surface sample was quite high, in the lower layers it was possible for part of the soil located near the plant roots to be practically pure.

In our opinion, this effect may have another explanation: some perennials resist the absorption of Cs^{137} from contaminated soil at the critical point; therefore, a kind of defense mechanism is activated. This is why in case of soil contamination with 12000 Bq / kg the plant absorbed less Cs^{137} than the same plant from the pure zone. It should also be noted that the concentration of K^{40} in the leaf of Spiraea japonica from the contaminated zone is almost 2 times higher than in the leaf taken from the pure zone. It creates an impression that it takes K^{40} to saturate itself to the maximum extent and no longer absorb Cs^{137}. (Or the plant under stress absorbs a lot of Potassium and therefore K^{40} which is not harmful to it and no longer absorbs Cs^{137} which is harmful). It is possible that for Spiraea japonica the critical value of soil contamination at which the plant ceases to absorbs Cs^{137} is much less than 12000 Bq / kg. It is extremely difficult to identify this value precisely subsequent experiments on the phytoremediation properties of fern under various soil contamination conditions confirmed this notion. (See Table 2)

Soil Bq/kg	Plant (Fern) Bq/kg
300	40
3000	200
12000	23
30500	12

Table 2

On the left side of the column the activities of Cs^{137} in the soil are provided, while on the right side there are the values of the activities absorbed by the fern (Bq / kg).

It is clear that this dependence is non-monotonous in nature. With the increase of soil contamination, the amount of Cs^{137} penetrating the fern and respectively its activity decreases sharply at a certain value.

To investigate the absorption of Cs^{137} by annual plants, we planted Chenopodium [6] seedlings in soils in vegetation pots that were contaminated with different concentrations of Cs^{137}. We planted the seedlings in early April and harvested them in early October.

The dependence of the activity of Cs^{137} and K^{40} absorbed by Chenopodium on the activity of Cs^{137} in the soil is given in Table 3.

Table 3

1–2 Columns show the activity of Cs^{137} and K^{40} in the soil (Bq/kg).

3-4 Columns show the activity of Cs^{137} and K^{40} in the plant (Bq/kg).

5-6 Columns show the transition factors of Cs^{137} and K^{40}

Table 3.

	Activity soil		Chenopodium		Transition Factor	
	Cs^{137}	K^{40}	Cs^{137}	K^{40}	Cs^{137}	K^{40}
I	1203	930	363	9 482	0.3	10,2
II	6067	982	583	4 747	0.1	4,83
III	6866	1011	903	4 271	0.1315	4,225
IV	8319	1068	624	3 920	0.075	3,67
V	21073	952	1 172	8268	0.056	3,68

This dependence has a distinctly non-monotonous nature which is well seen in the Cs^{137} absorption curve by the plant. The activity of Cs^{137} absorbed by increasing activity on relatively small soils reaches a maximum and then decreases, as in the case of perennials. But unlike perennials, further increase in Cs^{137} in the soil also increases its activity in the plant.

In our view, this is related to the onset of plant wilting, which deprives it of its ability to resist Cs^{137} penetrating the plant. Generally, the absorption of Cs^{137} by a plant is related to the fact that in its properties it resembles potassium and the plant is being deceived. It turns out that in October the plant will absolutely no longer be able to differentiate Cs^{137} from K^{40}. It is also possible that a plant absorbs Cs^{137} when it stops absorbing potassium.

The transition factor in the table is the ratio of the concentration (or activity) of plant-absorbed Cs^{137} or K^{40} in the soil to their concentration (or activity).

It should be noted that the activity of K^{40} absorbed by the plant also depends on the activity of Cs^{137} in the soil, although its activity and therefore the concentration in all pots are practically the same. The dependence curve of the activity absorbed by the plant has a minimum on the activity of Cs^{137} in the soil at the point where the first curve has a local minimum. An important circumstance must be highlighted: the curves of dependence on the concentration of Cs^{137} in plant-absorbed Cs^{137} and K^{40} in soil are parallel at high concentrations.

In order to study the dynamics of Cs^{137} penetration into the Chenopodium, we took plant samples in September and October 2018. (In the third and fifth vegetation vessels).

The following activities were observed in the sample taken from the third vegetation vessel:

23.08.2018 $G(Cs^{137})$ =458 Bq/kg $G(K^{40})$=3420 Bq/kg

21.09.2018 $G(Cs^{137})$ =506 Bq/kg $G(K^{40})$=4530 Bq/kg.

While in the sample taken from the fifth vegetation vessel the activities are the following:

23.08.2018 $G(Cs^{137})$ =128 Bq/kg $G(K^{40})$=6320 Bq/kg

21.09.2018 $G(Cs^{137})$ =1300 Bq/kg $G(K^{40})$=7200 Bq/kg.

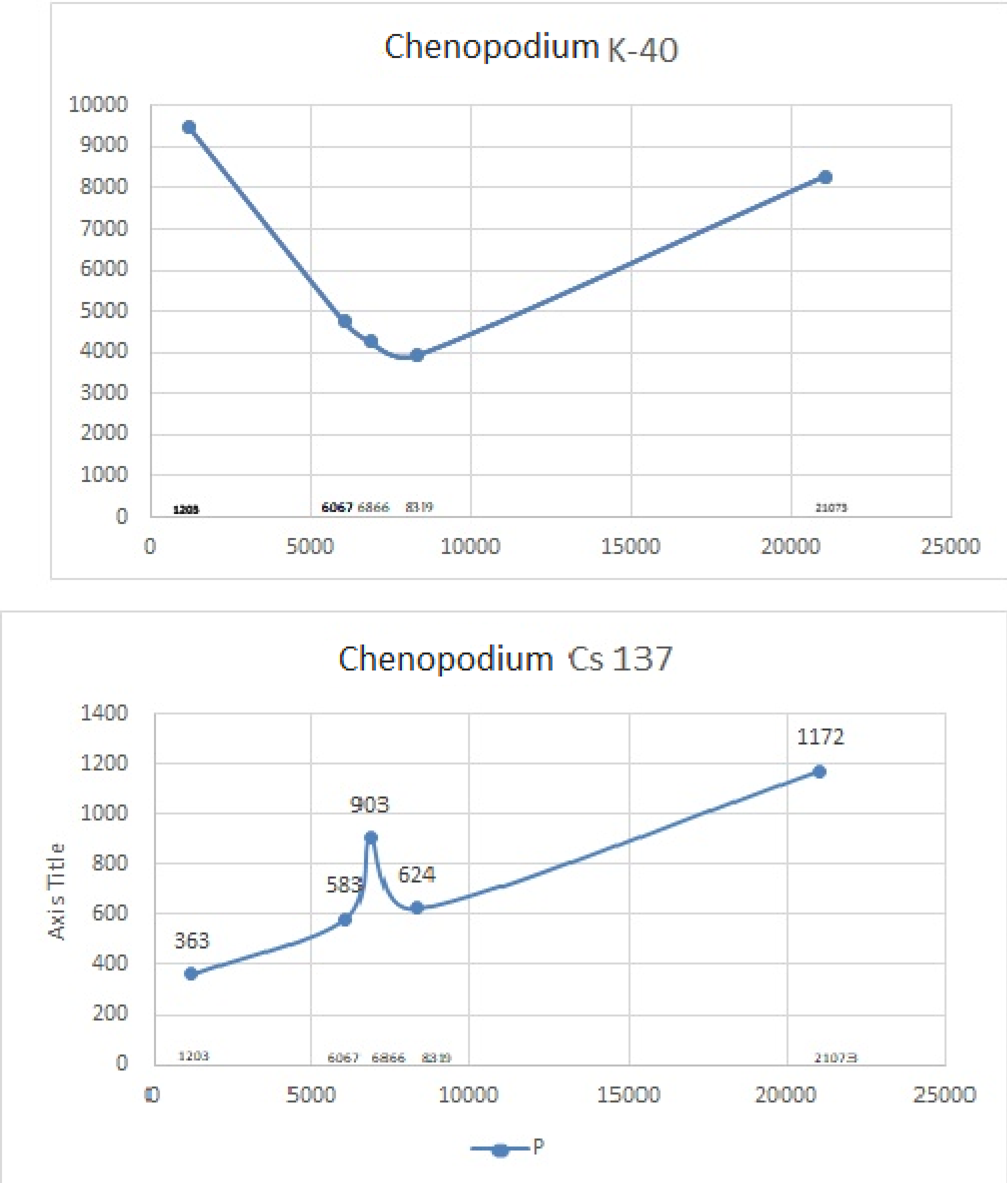

Fig.1. 1

The lower picture shows the dependence of the Cs^{137} activity removed by Chenopodium on the Cs^{137} activity in the soil. The upper figure shows the dependence of the K^{40} activity removed by Chenopodium on the Cs^{137} activity in the soil. The data from Table 3 are applied.

Under relatively low concentrations of soil contamination with Cs^{137} (third vegetation vessel, see Table 2) Cs^{137} penetrates the plant in large quantities also at the end of September, while the end of October the activity of Cs^{137} in it is slightly higher.

In the conditions of contamination with soil with quite a high concentration of Cs^{137}, Chenopodium at the end of September ((fifth vegetation pot)) still resists the penetration of Cs^{137}, while at the end of October it is characterized by high activity of Cs^{137}.

It can be concluded that both perennial and annual plants have the ability to resist the entry of Cs^{137} in the growth process. During the fall of temperature, the perennial plant hibernates and consumes very small amounts of water (it is known that metals enter the plant with water). Annuals, on the other hand, have the ability to with stand cold weather.

Experiments conducted in 2019 on the removal of radionuclides by plants involved the effects of biostimulants. We placed Chenopodium seedlings in practically the same soil contaminated with Cs^{137} (20,000 Bq/kg as of 2017) in early May. One of them was watered with a solution of lignohumate diluted with water at one-week intervals from the beginning of July. The obtained biomass was taken at the end of September. The material was subjected to gamma-spectrometric analysis.

In the sample taken from the fourth vegetation vessel, in which we did not use lingohumate, the following activities were observed:

28.09.2019 G(Cs^{137}) =620 Bq/kg G(K^{40})=7360 Bq/kg

In the fifth sample taken from the vessel in which we used lingohumate:

28.09.2019 G(Cs^{137}) =975 Bq/kg G(K^{40})=13725 Bq/kg

The use of lingohumate in the plant increased the absorption of both Cs^{137} and K^{40}, but the absorption activity of K^{40} increased significantly (2-fold), while the absorption activity of Cs^{137} increased by 57%.

The results of experiments conducted in 2020 raised many questions: no radionuclides were found in the soil near the surface of the vegetation vessel. Nevertheless Cs^{137} activity was observed in the plant.

Fourth vessel - in the soil G(Cs^{137}) =4.35 Bq/kg, G(K^{40})=1500 Bq/kg

In the plant G(Cs^{137}) =135 Bq/kg, G(K^{40})=13740 Bq/kg.

Fifth vessel - in the soil G(Cs^{137}) = 5 Bq/kg , G(K^{40})=1520 Bq/kg

In the plant $G(Cs^{137})$ =320 Bq/kg , $G(K^{40})$=12700 Bq/kg

This event has the only explanation: Radionuclides migrated deep into the soil and Chenopodium root extended at that depth and removed Cs^{137} from there.

Migration of radionuclides in the soil is a well-known phenomenon and is confirmed even by the migration of radionuclides in the soil of Georgia over time as a result of the Chernobyl accident. Having said that, it is surprising that in Anaseuli, in the soil of the former Radiation Ecology Area, which used to contaminated with radionuclides on purpose until 1992, there is still a high activity of Cs^{137} maintained near the soil surface. This may be due to the fact that the red soil (which is in Anaseuli) does not contain the bacteria that cause Cs^{137} to migrate, or there is loam near the surface in which radionuclides are trapped.

The present study is research is dedicated to investigating and explaining this difference to the extent possible.

References

1. Duncan Jackson, Michael Gilhen, Awadhesh Jha.International Scientific Workshop: Radioecology of Chernobyl Zone Slavutych, Ukraine: 2002. Science of the Total Environment, vol. 305(1-3), 2003, p.263-265.
2. F.A.Tikhomirov, A.I. Shcheglov, Main investigation results on the forest radioecology In the Kyshtym and Chernobyl accident zones, Science of The Total Environment, vol. 157(11), 1994, p.45-57.
3. Mouhamadou Moustapha Sy, Mark-Andre Gonze, Jean-Michel Metivier, Valerie Nicoulaud-Govin, Marie Simon Cornu. Uncertainly analysis in post-accidental risk assessment models: An application to the Fukushima accident. Annals of Nukliar Energy, vol.93, 2016, p.94-106.
4. Gongadze A.D., Imnadze P. M., Osidze I.G., Tsanava V.P., Gabunia Ts.G., Gogebashvili M.E., Ivanishvili N.I, Mamulaishvili I.G. Depth diagnostics of radionuclide burial place by using plant indicators. Nano Studies, vol.14, 2016, p. 85-90.

5. Gongadze A.D., Imnadze P.M., Tsanava V.P., Gogebashvili M.E., Ivanishvili N.I, Osidze I.G. Radionuclides migrating in perennial plants during their point distribution in the soil. Bulletin Georgian Academy of Agricultural Science, vol. 2(38), 2017, p.95-98.
6. Moogouei R, Borghei, M, Arjmandi R. Phytoremediation of stable Cs from solutions by Calendula alata, Amaranthus chlorostachys and Chenopodium album . Ecotoxicology and Environmental, vol. 74(7), 2011, p. 2036-2039.