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Accumulation and translocation peculiarities of ^{137}Cs and ^{40}K in the soil – plant system

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ABSTRACT

Long-term investigations (1996–2008) were conducted into the ^{137}Cs and ^{40}K in the soil of forests, swamps and meadows in different regions of Lithuania, as well as in the plants growing in these media. The ^{137}Cs and ^{40}K activity concentrations, the ^{137}Cs/^{40}K activity concentration ratio and accumulation, and translocation in the system, i.e. from the soil to plant roots to above-ground plant part of these radionuclides, were evaluated after gamma-spectrometric measurements using a high purity germanium (HPGe) detector.

Based on the obtained data, it can be asserted that in the tested plant species, the ^{137}Cs and ^{40}K accumulation, the transfer from soil to roots and translocation within the plants depend on the plant species and environmental ecological conditions. The ^{137}Cs/^{40}K activity concentration ratios in the same plant species in different regions of Lithuania are different and this ratio depends on the biotope (forest, swamp or meadow) in which the plant grows and on the location of the growing region. Based on the determined trends of statistically reliable inverse dependence between the activity concentrations in both soil and plants, it can be stated that the exchange of ^{137}Cs and ^{40}K in plants and soil is different. Different accumulations and translocations of investigated radionuclides in the same plant species indicate diverse biological metabolism of ^{137}Cs and its chemical analogue ^{40}K in plants. A competitive relationship exists between ^{137}Cs and ^{40}K in plants as well as in the soil.

1. Introduction

In the environment, ^{137}Cs is exclusively of anthropogenic origin. Among different released fission radionuclides, ^{137}Cs is the most significant as it contributes to long-term dosage to human populations. It belongs to a group of radionuclides which, under accidental situations, can be dispersed worldwide due to mass air dispersal. ^{137}Cs deposition in Lithuanian terrestrial and aquatic ecosystems is basically related to the global fallout and contaminated air masses from the Chernobyl NPP accident (Butkus et al., 1994; Mažeika, 2002; Butkus and Konstantinova, 2003; Morkūnienė et al., 2005; Lukšienė et al., 2006; Druteikienė et al., 2011; Lukšienė et al., 2012, 2014). An additional load of ^{134}Cs and consequently ^{137}Cs deposited in Lithuanian terrestrial ecosystems occurred after the Fukushima Daiichi NPP accident as well (Maceika et al., 2011). Over recent decades, evident changes in the approach to radiation protection of non-human species from ionizing radiation have occurred. Furthermore, long-term predictions of the mobility and bioavailability of ^{137}Cs are required due to its penetration into the food chain. ^{40}K is a typical lithophilic element and its geochemistry could be similar to that of ^{137}Cs because they are both of the same valence state, +1.

Plants in the terrestrial ecosystem play an important role in the spread of technogenic radionuclides because radionuclides getting into soil become involved in processes of biological cycling which take place in the soil-plant system (Alexakhin, 1963). Analysis of scientific data shows an insufficient level of investigation into problems such as the transport of radionuclides between different parts of plants and from the root system to the above-ground plant parts (Tyson et al., 1999; Fortunati et al., 2004). A scarce data base on the ^{137}Cs transfer in the soil-plant system from roots to above-ground parts of plants is known. Investigations by many authors in the field of radionuclide dispersion in the soil-plant system are mostly confined to the analysis of radionuclide mobility in soil

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(Forsberg et al., 2000) or examination of radionuclide transfer in the soil-plant system in the above-ground part (Brambilla et al., 2002; Wang et al., 1998; Drissner et al., 1998; Toal et al., 2002).

Dispersion of radionuclides, including ^{137}Cs in the soil-plant system, can be predetermined by many factors (Alexakhin and Korneev, 1991). Some of main factors could be highlighted: physical-chemical features of radionuclides; physical-chemical features of the soil; biological features of the plants; biological, ecological and geological features of the environment; and meteorological conditions.

Investigations into the peculiarities of ^{137}Cs accumulation and transfer in ecosystem components are of great importance to the determination of zones of enhanced contamination with this radionuclide, to the evaluation of its spread in the terrestrial ecosystem, and to the assessment of phytoremediation and self-rehabilitation processes in territories polluted with this radionuclide (Bystrzejewska-Piotrowska and Nowacka, 2004). Radionuclides in the soil-plant system can behave similar to their stable analogues, therefore the relationship of ^{137}Cs and its chemical analogue K in the metabolism of the soil-plant system can help in the understanding of mechanisms of ^{137}Cs transfer from soil to plant roots (Broadley et al., 1999; Jones et al., 1998; Bystrzejewska-Piotrowska et al., 2005). Some authors indicate an existence of a competitive relationship between ^{137}Cs and K in plant mineral metabolism (Ganzha et al., 2013). Radionuclide recycling in the soil-plant system governed by radionuclide accumulation and fixation in soil is of great importance to the assessment of their dispersion in the environment.

The aim of this work was to investigate the accumulation of ^{137}Cs and its chemical analogue ^{40}K, as well as metabolic causal relationship between these radionuclides in the tested plant species in different Lithuanian regions under different ecological conditions; as well as to evaluate and compare peculiarities of the transfer of studied radionuclides in the soil-plant system from roots to the above-ground parts of plants.

2. Methodology

Soil and perennial plant samples were collected in forest, swamp and meadow biotopes in the vicinity of Ignalina NPP in 1996, 1998, 2000, 2002, 2007, 2008, and in the regions of Ignalina, Varėna and Plungė in 1996–1998, 2002 and 2007 (Fig. 1). The samples were collected in the same place once a year in July–August. In total, 98 plant and 28 soil samples were taken from the Ignalina NPP vicinity and 68 plant and 43 soil samples from Ignalina, Varėna and Plungė regions. The ^{137}Cs contamination levels were different in these regions after the Chernobyl NPP accident. The Plungė region was contaminated the most with this radionuclide, while Ignalina region suffered the least pollution (Jefanova et al., 2014).

The dominant perennial year-round vegetation species in the studied areas are as follows: Mosses - stair-step moss (*Hylocomium splendens* (Hedw) Shimp), peat moss (*Sphagnum* sp.) and meadow moss. Grasses - rough small-reed (*Calamagrostis arundinacea* L.), waterarum (*Calla palustris* L.), brake (*Pteridium aquilinum* (L) Kuhn), common cock's-foot (*Dactylis glomerata* L.), common Saint-Johns wort (*Hypericum perforatum* L.), common wormwood (*Artemisia vulgaris* L.). Low-growing perennial shrubs - heather (*Calluna vulgaris* (L.) Huul.), bilberry (*Vaccinium myrtillus* L.). A point of note, *C. arundinacea* and *D. glomerata* have fibrous roots, while all other tested plants have a taproot system.

The whole plant, its above-ground part and the roots were studied separately. The ^{137}Cs and ^{40}K activity concentration in the whole plant, its above-ground part and roots were stated in Bq/kg for dry mass. A total of 64 samples of the above-ground parts of the plant and roots were collected under natural conditions and analysed separately. Soil samples were collected with a special metal ring (diameter – 14.5 cm; height – 5 cm) in the 5 cm surface layer. The samples for the evaluation of the soil core were taken by an Eijkelkamp corer. The amount of organic mater ranged from 8.2 to 18.5% in forest soil, from 88.3 to 93.3% in swamp soil, and from 3.1 to 5.4% in meadow soil, while the soil pH values varied from 3.8 to 7.5, 2.5 to 3.7 and 3.9 to 4.5 respectively.

Data on the ^{137}Cs activity concentrations in plants and soil, depending on the year of the investigation, were detailed in our previously published articles (Lukšienė et al., 2012, 2013; Jefanova et al., 2014). Data on the dependence of the ^{137}Cs activity concentration in the soil and plant roots, as well as the dependence of ^{137}Cs activity concentration between plant roots and above-ground parts were presented in Lukšienė et al. (2013).

The whole plant and its separated parts (roots and above-ground parts of sampled test-plants) were dried and mineralized at 400 °C.

Gamma-spectrometric measurements were carried out using a high purity germanium (HPGe) detector coupled to a MCA Inspector 2000 with Genie 2000 gamma-spectroscopy analysis software (Canberra Industries, USA). The detector was of the GMX series by Ortec, USA, with a relative efficiency of 30% and energy resolution of 1.72 keV at 1333 keV (Gudelis et al., 2000).

Obtained data were analysed statistically using the program STATISTICA 8.0 (StatSoft Inc., Tulsa, Oklahoma, USA), t-test at the significance level of $p < 0.05$.

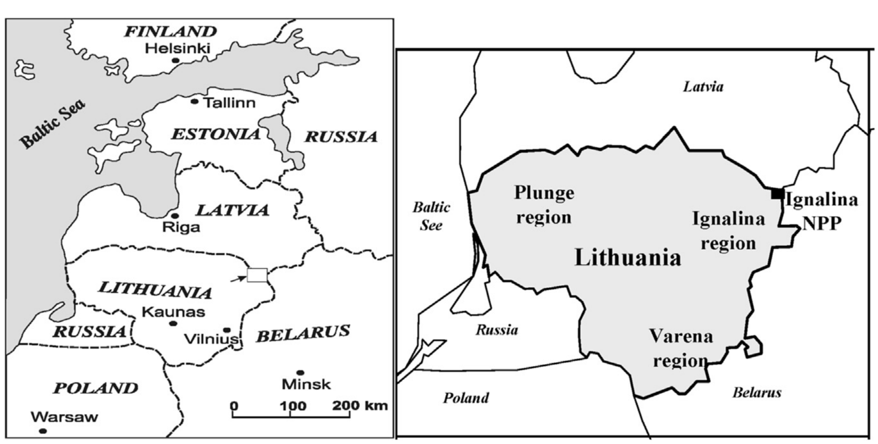

Fig. 1. Geographical location of soil and plant sampling grounds.