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^{137}Cs and K annual fluxes in a cropland and forest ecosystems twenty-four years after the Chernobyl accident

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A B S T R A C T

Biological cycles of the Chernobyl originated cesium-137 (^{137}Cs, radiocesium) and the natural potassium (K) in oak, birch, and pine forest, and wheat cropland in Russian Federation, approximately 500 km northeast of the Chernobyl Nuclear Power Plant, were subject to a multiyear monitoring. By 2010, the annual return of ^{137}Cs from forest vegetation to the soil in dead tree components still exceeds its annual accumulation in the tree phytomass by a factor of 4–6, apparently due to residual surface contamination in the external bark and the ongoing process of tree stand decontamination following the initial fallout. In the cropland, both ascending and descending fluxes of ^{137}Cs are close to the steady state. The annual accumulation of ^{137}Cs in the tree biomass was the highest in the oak forest and the lowest in the pine forest. The annual K accumulation was the highest in the cropland and the lowest in the pine forest.

1. Introduction

A quantitative assessment of biological cycles of artificial (technogenic) radionuclides is a fascinating topic for biogeochemistry. Some aspects of the radionuclide behavior as a apart of natural cycles on the ecosystem scale were first studied by Klechkovskii (1956) and Timofeev-Ressovskii (1962), followed by Tikhomirov et al. (1972, 1994) and Alexakhin and Tikhomirov (1976, 1977, 1991). Many later researchers presented comprehensive material on the biological cycles of ^{137}Cs and ^{90}Sr in forest environments due to the 1986 Chernobyl accident (Shcheglov et al., 1996, 2006; Guillitte et al., 1994; Shaw et al., 1996; Thiry et al., 2009). Currently, detailed studies on the radiocesium fate in forest ecosystems are being conducted in Japan in connection with the 2011 accident at the Fukushima Daiichi Nuclear Power Plant (Kuroda et al., 2015; Yoshihara et al., 2014; Imamura et al., 2017). In particular, Yoschenko et al. (2016, 2017) analyzed the ascending and descending fluxes of cesium-137 in the Fukushima forests after the fallout. It is still a question, however, as to whether or not the ^{137}Cs from the 1986 ("Chernobyl") and 2011 ("Fukushima") fallout is more readily available for trees compared to stable cesium, or potassium, and what are principal differences (if any) in their biological cycle depending on ecosystem and time since the fallout.

Biological cycles of natural potassium and other nutrients in mature forest ecosystems are normally in a steady state, i.e., the amount of a nutrients being accumulated annually in the stand (ascending flux) is comparable to that returning to the soil surface with litterfall, stemflow, throughfall, etc. (descending flux) (Bazilevich et al., 1978; Likens et al., 1994; Gosz et al., 1976). Long-term studies conducted after the Chernobyl accident showed that the radiocesium cycle depends on multiple factors, such as type of fallout, type of landscape, ecosystem productivity, and soil properties. For example, annual root uptake of ^{137}Cs in the forest plants growing in wet lowlands with organic soils soon enters a quasi-steady state with its annual return to the soil through litterfall (Shcheglov et al., 2001; Shaw et al., 1996). In the first decade after the accident, annual return of radiocesium to the soil exceeded its root uptake, because of natural decontamination processes in the stand and release of the radionuclides initially retained in the exposed tree parts (Sanzharova et al., 1994; Sak, 1997; Perevolotskii, 2006). For the same reason, key parameters of the ^{137}Cs and ^{90}Sr biological cycle can be different from the corresponding stable isotopes or chemically similar pairs of elements, such as potasssium and calcium (Yoshida et al., 2004; Shcheglov et al., 2001).

It may be assumed that with the passage of time, the biological and ecological (biogeochemical) cycles of artificial radionuclides will become more similar to the cycles of natural stable isotopes and chemical analogs, and finally reach the steady state in the soil-plant system (Lipatov et al., 2003; Shcheglov et al., 2001). The dynamics and time scale of such process during the transition period can only be clarified by analyzing experimental and monitoring data on the ecosystem scale.

This study compares the biological fluxes of ^{137}Cs and natural potassium in one cropland and three forest ecosystems affected by the Chernobyl fallout in 1986. We considered the ^{137}Cs and potassium

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content in the tree structures and tried to assess the relative contribution of each tree structure to the Chernobyl derived ^{137}Cs and natural K inventory and fluxes through the ecosystems.

2. Materials and methods

The data were obtained as a part of the long-term radioecological monitoring study that has been carried out in the Tula Oblast in the Russian Federation, some 500 km from the Chernobyl Nuclear Power Plant from 1999 to 2010. The investigated area location and layout are shown in Fig. 1. General methodological approach to the study is presented in Fig. 2, with the details described below.

By 2010, the total ^{137}Cs deposition in the 0–15 cm soils layer was 163 kBq/m^2 in the cropland and some 300 kBq/m^2 in the soils of the forest sites (Table 1). The difference in deposition is likely due to a more pronounced initial interception of the fallout by the forest lands compared to open areas (Shcheglov et al., 1996, 2001, 2004). Also, deep-plowing of the cropland after 1986 could have transferred a portion of ^{137}Cs to below the 0–15 cm root abundant layer (Lipatov et al., 2003).

The test sites were established in three forest ecosystems, with the domination of either oak (*Qercus robur* L.), birch (*Betula pendula* Roth) or pine (*Pinus sylvestris* L.). The age of the forest ecosystems was about 65 years by 2010. The only test site with non-forest ecosystem was established in a commercial cropland seeded with spring wheat. All the

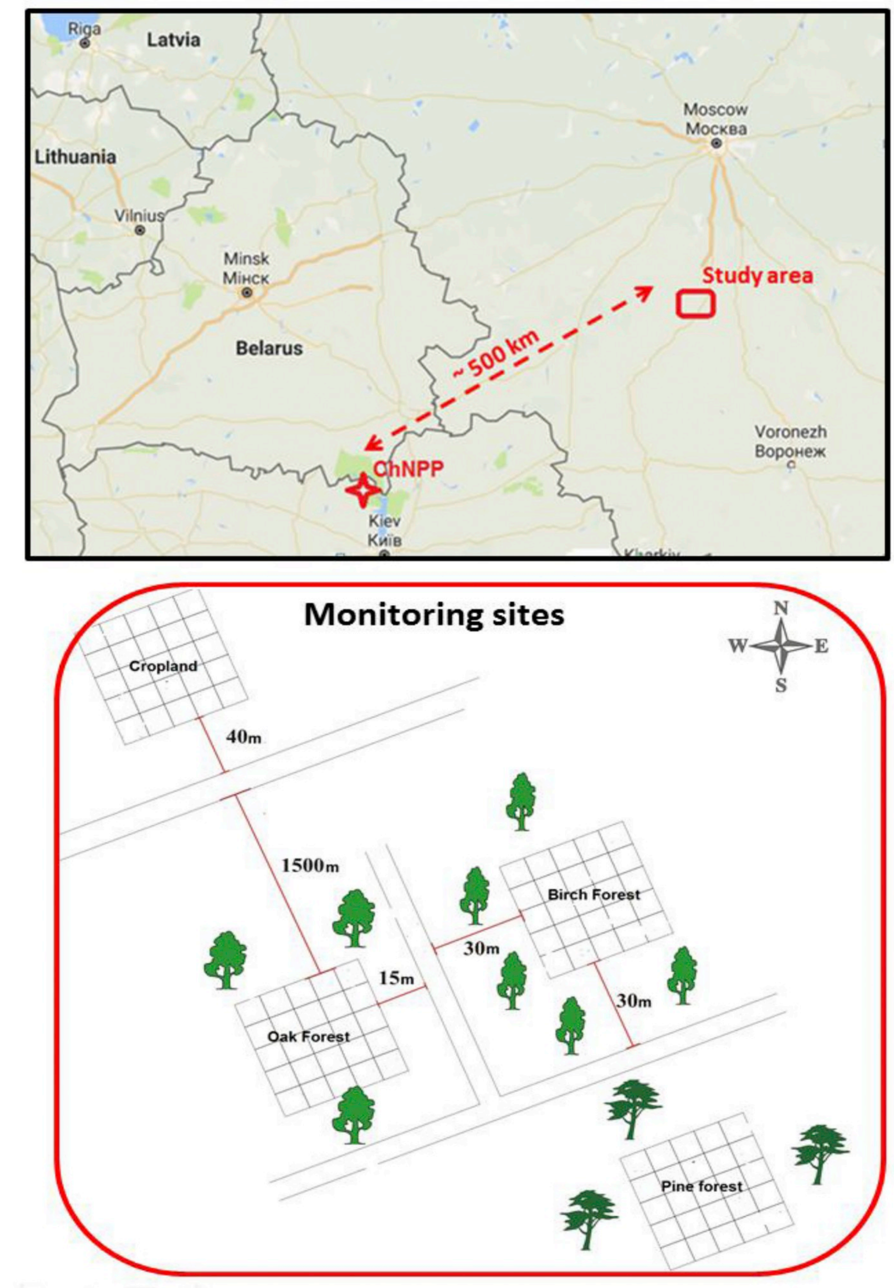

Fig. 1. The site location and layout.