Accumulation of ^{90}Sr by Pinus sylvestris and Betula pendula in the zone of radioactive contamination (East Ural Radioactive Trace, Russia)

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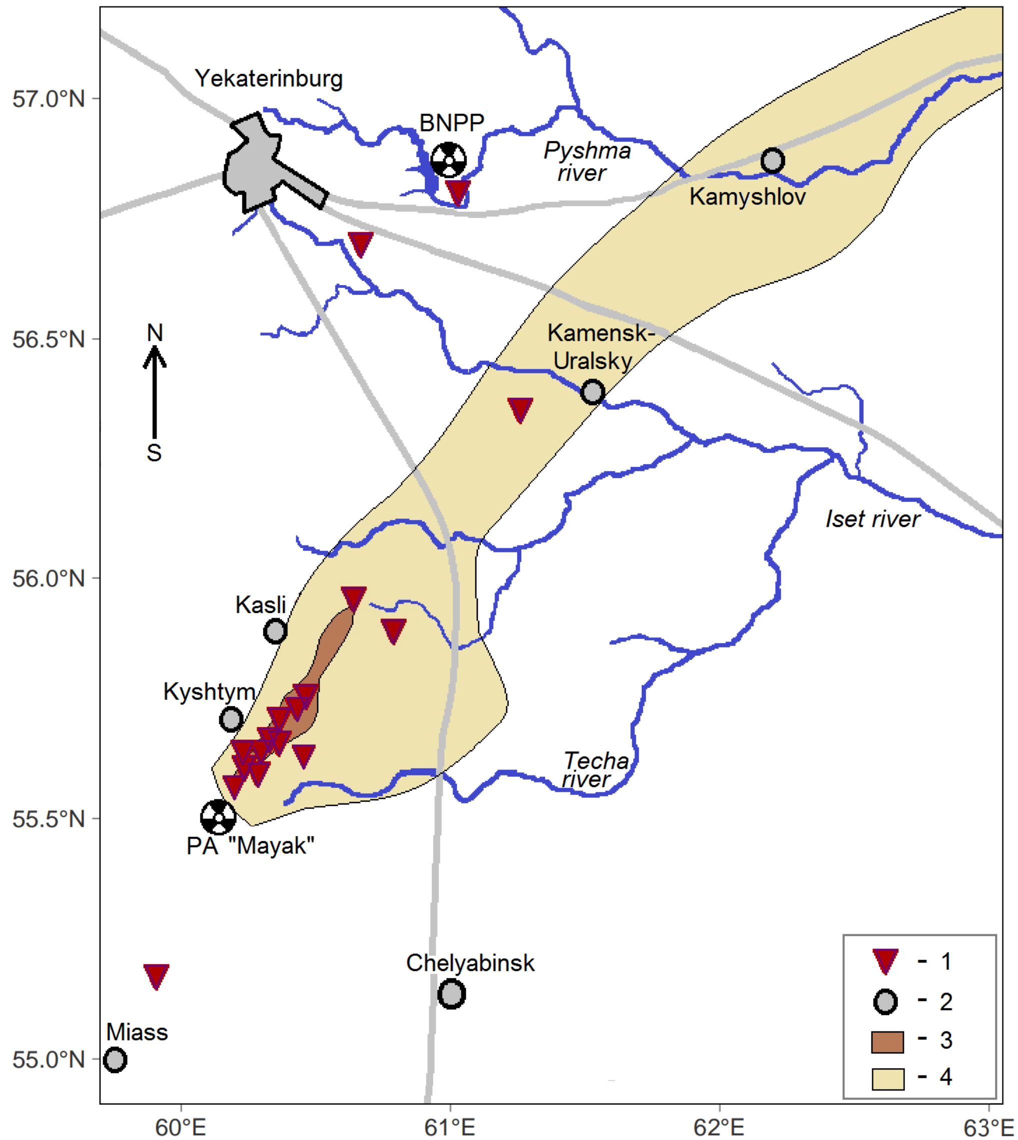

The East Ural radioactive trace (EURT) was formed in 1957 as a result of the so-called Kyshtym accident at the "Mayak" Production Association. This territory is a narrow sector oriented in the north-east direction within more than 100 km length and 23,000 km^2 square. ^{90}Sr was prevailed among long-lived radionuclides. This territory belongs to the subzone of the forest-steppe. Birch and pine-birch forests dominate in the EURT. Varieties of gray forest soils prevail in the soil cover.

A wide range of soil pollution levels, heterogeneity of topographical and ecological terms allows to study the patterns of radionuclides distribution in components of ecosystems.

Fig. 1 The study area: 1 – reference sites; 2 – cities. Densities of soil contamination with ^{90}Sr on the EURT zone : 3 – 70,000–100 kBq·m^2; 4 – 100–3 kBq·m^2.

Research purpose

Investigation of the patterns of ^{90}Sr accumulation by woody plants (*Pinus sylvestris* and *Betula pendula*), which have been growing in the gradient of radioactive contamination.

Material and methods

We have selected test sites in automorphic territories located at a distance of 5–30 km from the epicenter of the accident (Fig. 1). The soil contamination density decreased with distance from 70 to 0.4 MBq/m^2. Control sites (0.002 MBq/m^2) were selected outside the EURT area. Few Scots pine stands were found in the head part of the EURT only in areas where the soil contamination density does not exceed 10 MBq/m^2. We took samples of soils and aboveground organs of trees: leaves (needles), small branches 1–5 years old, large branches 5+ years old, trunks (wood, bark).

The ^{90}Sr content in soil and plant samples was determined by the radiochemical method. The beta activity of the preparations was measured on a UMF-2000 radiometer (Russia) with a lower detection limit of 0.2 Bq.

Results

The concentrations of ^{90}Sr in air-dry matter of pine and birch aboveground organs increase with increasing the soil contamination density. Concentrations of ^{90}Sr in leaves and small branches of birch are higher than in trunks (fig. 2). Specific activities of ^{90}Sr in pine organs are equally.

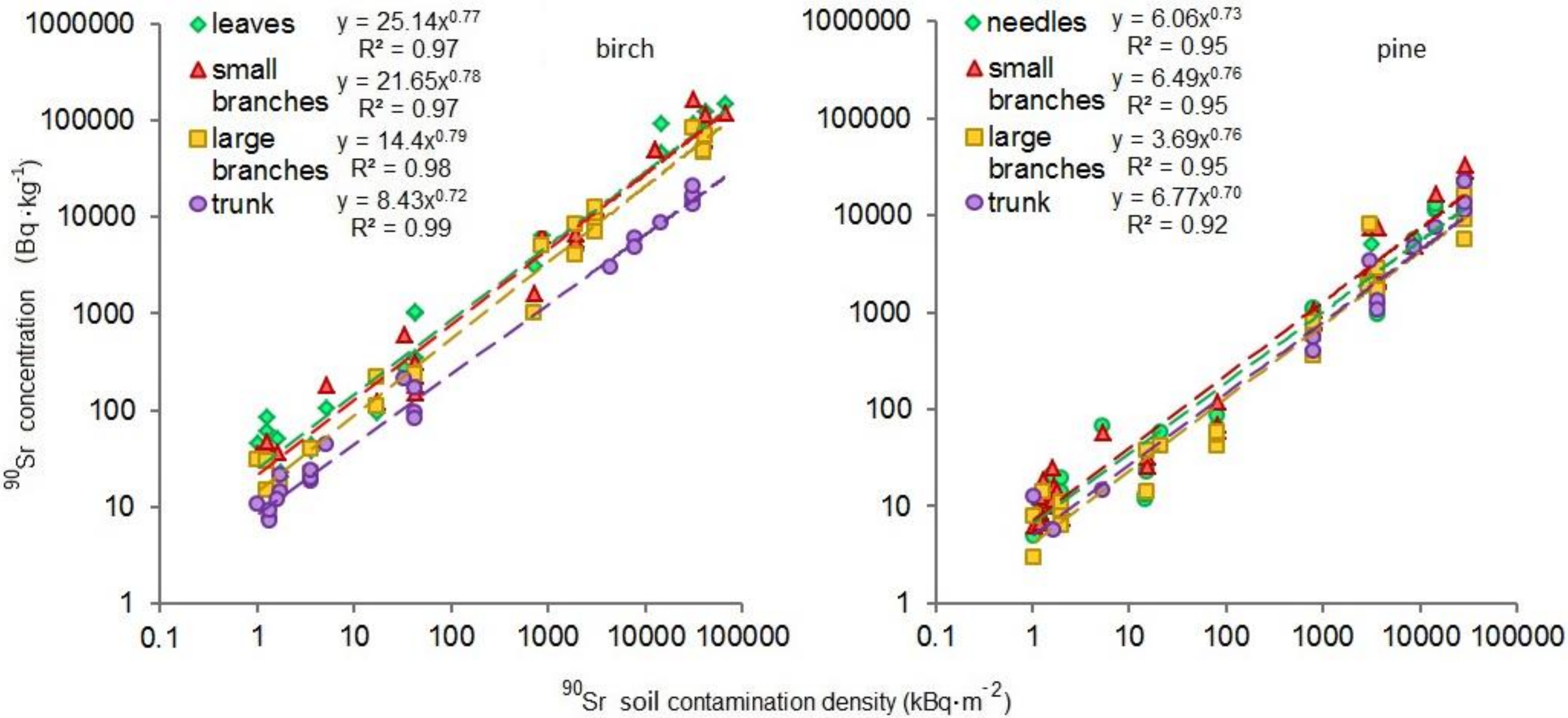

Fig.2 Dependence of ^{90}Sr concentrations in the birch and pine aboveground mass on the soil contamination density

Table 1. Mineral and ^{90}Sr accumulation in aboveground organs of trees

Species	Organ	Ash, %	^{90}Sr concentration, $kBq*kg^{-1}$ of air-dry matter, min-max	T_{ag}, $n*10^{-3}kg^{-1}m^2$ min-max
Betula pendula	Leaves	5.4±0.5	0.02-180.4	1.61-64.9
	Small branches	2.7±0.6	0.035-218.0	1.51-37.1
	Large branches	2.4±0.3	0.014-80.8	1.13-28.8
	Trunk	0.6±0.2	0.007-155.2	0.58-11.7
Pinus sylvestris	Needles	2.3±0.3	0.004-22.3	0.24-12.0
	Small branches	1.8±0.4	0.006-33.4	0.52-14.3
	Large branches	1.1±0.1	0.003-16.0	0.18-10.9
	Trunk	0.6±0.2	0.006-22.3	0.27-11.8

The values of T_{ag} of ^{90}Sr obtained by us for woody plants (Table 1) are comparable with the ranges of variability of this indicator given for the territories of Russia and Ukraine contaminated with fallouts from the Chernobyl accident (IAEA, 2009), as well as those calculated from the data (Karavaeva et al., 1994; Yushkov, 2000) for the background areas and the zone contaminated as a result of the Kyshtym accident.

Aggregated transfer coefficients (T_{ag}) in the above-ground mass of birch and pine decrease with increasing soil contamination density (Fig. 3). A relative decrease of T_{ag} with an increase in the density of soil contamination with radionuclides was also noted in other studies (Beresford, Wright 2005, Molchanova et al., 2014; Mikhailovskaya et al., 2018). This phenomenon can be associated with the influence of at least two factors.

First, the reason for the relative decrease in the accumulation of radionuclide by the aboveground mass of plants may be radiation damage to the roots. High dose loads on the root system can lead to inhibition of root growth and a decrease in their storage capacity (Tikhomirov et al., 1975). There are also data on changes in the accumulation of stable chemical elements in the aboveground mass of plants under the influence of a high level of radioactive contamination of soils (Chankina et al., 2007). It has been shown that, even 60 years after the Kyshtym accident, most of ^{90}Sr is in the upper 20 cm soil layer (Mikhailovskaya, Pozolotina, 2020) and creates a radiation load on root systems that exceeds the background values by 3–4 orders of magnitude (Karimullina et al., 2018).

Secondly, a significant factor can be a relatively large contribution of aerial pollution of plants in areas with a level of soil pollution close to background values. The wind transport of fine dust influenced the spatial redistribution of radionuclides on the territory of EURT only in the first 3 years after the accident (Makhonko, 1990). The intake of ^{90}Sr in the standard emissions of the “Mayak” PA has always been very small compared to the level of pollution in the zone closest to the epicenter of the accident (Bakurov, 2007). Currently, global fallouts of ^{90}Sr from the atmosphere are estimated at 3 $Bq \cdot m^{-2}$ per year, while near operating nuclear plants they can reach 5.2–70 $Bq \cdot m^{-2}$ per year (Yearbook, 2017, 2020). Therefore, in areas with a low level of pollution, routine emissions from nuclear enterprises can make a significant contribution to radioactive contamination of soils and especially vegetation cover, as a result the relative indicator T_{ag} increases (Mikhailovskaya et at., 2015; Mikhailovskaya, Pozolotina, 2020).

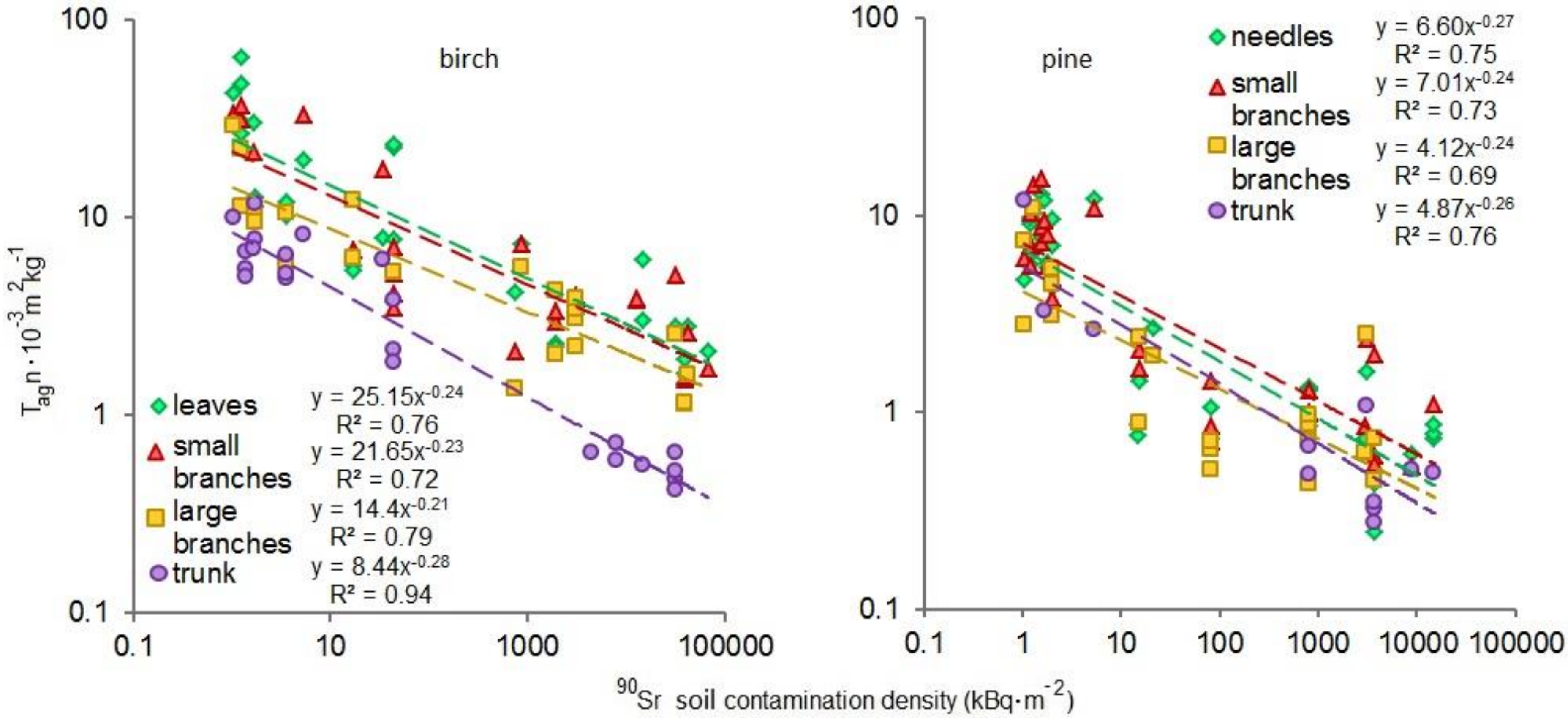

Fig. 3. Dependence of ^{90}Sr aggregated transfer factors (T_{ag}) in the aboveground mass of birch and pine on the density of soil contamination

Table 2. Brief characteristics of trees trunks from the EURT zone and distribution of ^{90}Sr in them (20-25 year)

	Part of the trunk	Mass fraction (air-dry matter), %	Ash content, %	Share of ^{90}Sr from the content in the trunk, %	T_{ag}, n $10^{-3}kg^{-1}m^{2}$
Betula pendula	Bark	17.45±2.75	1.58±0.33	45.28±10.97	3.17±1.61
	Wood	82.55±2.75	0.43±0.12	54.71±10.99	0.71±0.17
	Trunk *	100	0.58±0.19	100	1.09±0.20
Pinus sylvestris	Bark	25.8±2.6	1.99±0.55	52.00±11.37	1.27±0.38
	Wood	74.2±2.6	0.31±0.01	48.00±11.37	0.38±0.04
	Trunk *	100	0.76±0.18	100	0.62±0.16

Note: * Trunk without division into bark and wood.

The mass fraction of the bark in all trunks was on average 17.5–25.8% (Table 2). The ash content in the birch wood amounted to 0.71% and in the pine was 0.38%. The ash content of the bark was 3.6–6.4 times higher. The T_{ag} of ^{90}Sr in the bark were higher than in the wood, it is associated with the different degrees of their mineralization. Although the mass fractions of the bark were on average 17.5–25.8%, they contained 45–52% of the total amount of the ^{90}Sr accumulated in the trunks. The T_{ag} of ^{90}Sr in the birch was higher than in the pine.

Conclusion

1. *Betula pendula* accumulates ^{90}Sr in larger quantities than *Pinus sylvestris*.

2. Concentrations of ^{90}Sr in leaves and small branches of birch are higher than in trunks. Concentrations of ^{90}Sr in pine organs are equally.

3. The concentrations of ^{90}Sr in air-dry matter of trees were increased with increasing soil contamination density in accordance with power function ($y=ax^b$).

4. The values of T_{ag} of ^{90}Sr obtained by us for woody plants are comparable with the ranges of variability of this indicator given for the territories of Russia and Ukraine contaminated with fallouts from the Chernobyl accident, the Kyshtym accident and for the background areas.

5. The T_{ag} of ^{90}Sr in the bark were higher than in the wood, it is associated with the different degrees of their mineralization.

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Thank you for your attention!