INTRODUCTION

Migration of $^{137}$Cs in water was the focus of intense studies within half a century in studying the pollution of Earth’s biosphere by artificial radionuclides (ARN). Most of the studies was carried out in water bodies in the northern middle latitudes, where major radiation accidents in the XX century took place. 2011 Fukushima NPP accident was accompanied by a release of radioactive iodine and cesium isotopes into the atmosphere. With accident products released into the atmosphere, the “distance as protection” factor fails to guarantee the absence of radioactive pollution of biota in terrestrial and aquatic ecosystems at considerable distances from the radiation emission. Fish pollution by Chernobyl $^{137}$Cs in water bodies of Western Europe [13, 19] was often higher than that in the Kiev Reservoir, which is locted ~30 km from the destroyed ChNPP unit and receives Dnieper water polluted by $^{137}$Cs. The data on $^{137}$Cs migration in middle-latitude water bodies cannot be used to characterize the conditions in northern water bodies because of the natural and climate differences. Therefore, the regularities in $^{137}$Cs migration in water bodies of subarctic regions require special studies.

The objective of this study was to examine the response of a watershed—water body system to a long-time presence of $^{137}$Cs, resulting in changes in the rate of natural water purification from this radionuclide over time. The focus of this study was the correlation of this process with landscape and climate conditions on watersheds in rivers in East Fennoscandia, which embraces the area from Lapland (Finland) and Kola Peninsula (Northern Russia) to the Gulf of Finland and Karelian Isthmus in the south with a conventional boundary from the east along the line the White Sea—Onega Lake—Ladoga Lake.

Studying $^{137}$Cs migration in water under the landscape and climate conditions in Eastern Fennoscandia included two stages: the focus of the first stage was the $^{137}$Cs pollution of surface waters and their purification with time, while the second stage specified the character of surface water pollution and its purification from Chernobyl $^{137}$Cs at a short-time exposure of this radionuclide on a watershed.

The pollution of water bodies by global $^{137}$Cs is the process extended in time (approximately, 1961–1965), whereas the Chernobyl $^{137}$Cs pollution is an almost instantaneous process. In late April 1986, the rivers and lakes in the north of the Eastern Fennoscandia were still covered by ice, while water bodies in its southern part were at the stage of spring flood and water warming. $^{137}$Cs water pollution in rivers and lakes in the northern part of the region started only after the melting of ice and the inflow of melt water into water bodies.

In the north of the region (north of 64°N), Chernobyl $^{137}$Cs fallout was near its global rate of ~1.7 kBq/m², while the density of its local fallout in the southern part was ~64 kBq/m² [1, 3, 7, 20]. $^{137}$Cs concentrations in water bodies, their many-year dynamics, and correlation with landscape and climate conditions on watersheds were assessed in [5, 7, 12, 21]. $^{137}$Cs in the litho- and hydrosphere of the Earth, except for some local areas, is represented by $^{137}$Cs of local fallouts from atmospheric nuclear tests (1961–1963) and $^{137}$Cs release from 1986 Chernobyl NPP accident. The study incorporated the literary data on $^{137}$Cs content of river and lake waters [1, 5, 7, 14, 16], as well as data of the authors of this article on
The dynamics of the concentration of global $^{137}\text{Cs}$ in surface water was studied based on $^{137}\text{Cs}$ monitoring data in water bodies in the northern and southern parts of the Eastern Fennoscandia. The sample (figure) included data on $^{137}\text{Cs}$ concentration in water bodies of the Kola Peninsula, Karelia [5, 12], and the bordering Finland over 1974–1985 [13–16, 21]. $^{137}\text{Cs}$ concentration in water of Russian lakes and Finnish rivers at the appropriate moments in the time series was represented by mean values.

In 1968, $^{137}\text{Cs}$ concentrations in water in lakes Onega, Vygozero, and Rugozero were 18.5, 14.8, and 17.4 (with a mean of $16.9 \pm 1.9$) Bq/m$^3$ (this value in the figure is attributed to 1968) [12]. $^{137}\text{Cs}$ concentrations in Lake Imandra water, which amounted to 6.7, 6.7, 8.9, 4.8, and 6.3 Bq/m$^3$ in 1974–1979, respectively, were averaged along with $^{137}\text{Cs}$ concentrations in water bodies in Finland [21] at the same observation dates. At the end of the time series (figure), the values of $^{137}\text{Cs}$ concentrations in water never exceeded 3–4 Bq/m$^3$. The results of observations (1968–1985) of $^{137}\text{Cs}$ concentration in water were approximated by an exponential function with a half-time $T$, during which radionuclide concentration in water decreases by half:

$$C_t = C_0 \exp(-0.693t/T),$$

where $C_t$ is $^{137}\text{Cs}$ concentration in water, Bq/m$^3$, over time $t$, $t$ is the year of observation; $C_0$ is $^{137}\text{Cs}$ concentration in water in 1968, equal to 17.0 Bq/m$^3$; $T$ is the half-time of $^{137}\text{Cs}$ concentration decrease in water, equal to 6.5 years.

The process of natural purification of lake–river systems in the region from global $^{137}\text{Cs}$ proceeds with half-time $T$ equal to 6.5 years.

According to data in [13], in 1965–1985, water purification in the rivers of Kemijoki (Northern Finland) and Kymijoki (Southern Finland) from $^{137}\text{Cs}$ proceeded with decay half-time of 10.4 and 6.9 years respectively. The above estimate $T = 6.5$ years is near the lower boundary of the interval 6.9–10.4 years. There are no rivers in the Russian part of the Eastern Fennoscandia that can be compared with Kemijoki in terms of watershed position and area and runoff volume. Therefore, the values of $T$ for them should be less than those for Kemijoki.

The longest rivers in Eastern Fennoscandia are classified as median (their drainage area is 5–50 thou. km$^2$). The rivers flow out of lakes or through them in their middle (lower) reaches. With this feature of their runoff, the individual values of $T$ for the rivers should not deviate far from their mean value of 6.5 years. Large rivers drain deep aquifers, which contain no artificial radionuclides (ARN). The polluted water in them is diluted by clear water from larger depths. Such effect does not work in small rivers. Therefore, ARN concentrations in water in small and median rivers are more dependent on the landscape and climate conditions on watersheds.

Water of Onega Lake (the runoff of the Svir R.) was purifying from global $^{137}\text{Cs}$ with $T = 8$ years [2]. This value is somewhat higher than $T = 6.9$ years [13], which characterizes the purification from $^{137}\text{Cs}$ in the short Kymijoki R., flowing out of the deep Lake Paijanne ($H_{\text{av}} = 10$ m).

The properties of soils and landscapes, as well as the climatic features of the Eastern Fennoscandia had their effect on $^{137}\text{Cs}$ inflow from watersheds into river network. In the direction from the north of the Kola Peninsula to the southern part of Karelia and Karelian Isthmus, the mineralization of surface water increases, the mountain landscape changes to lowlands, and the