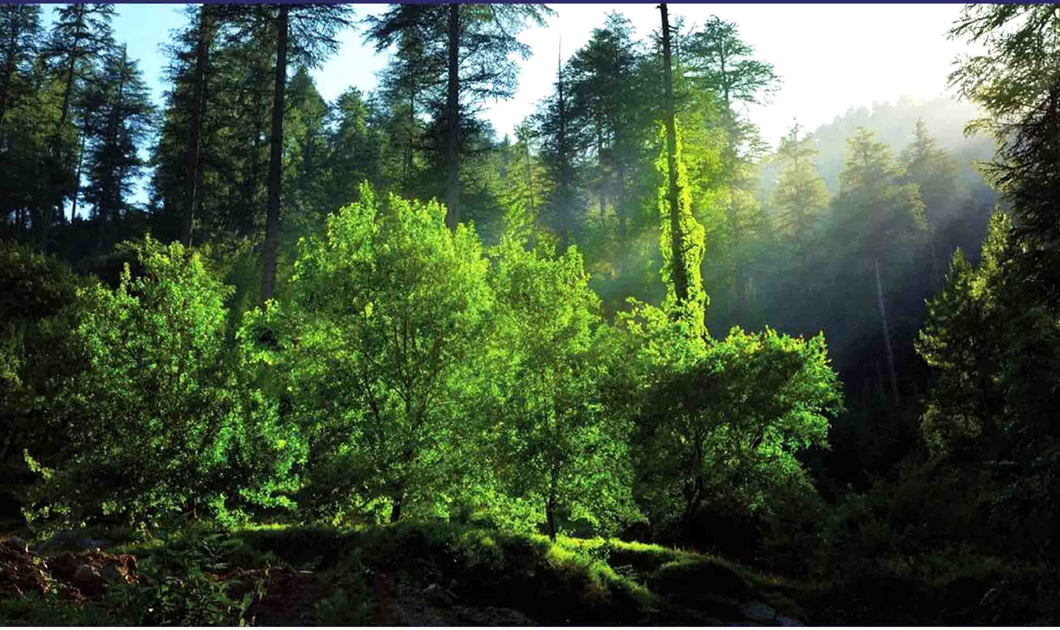

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Radioecological research on ecosystems of Beloyarsk NPP on the Ural

The experience of radioecological research in the zone of influence of the Beloyarsk Nuclear Power Plant

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Introduction

Wide scale tests of nuclear weapons in the mid-XXth century and the development of nuclear industry and nuclear power engineering were accompanied with the transfer of artificial fissile materials in large amounts to a biosphere. Therefore radioactive substances and their radiation became one of the most important ecological factors that influence the biota. An integrated task of the radioecology (the science studying the interaction of living organisms among themselves and with the environment where they live in conditions of a higher radiation background) is to ensure a radiation safety of biosphere including a human being ("On behavior..., 1956; Timofeeff-Ressovsky, 1957, 1961, 1968; Peredelskiy, 1957; Platt, 1957; Polikarpov, 1964; "Methods of radioecological... 1971; Odum, 1971; Aleksakhin, 1982, 2006). One of the individual sections of this science is the continental radioecology. It investigates migration processes and biological effects of radionuclides in biogeocenosis of land and inland water reservoirs (Aleksakhin, 1976; Kulikov, Molchanova, 1981; Kulikov, Chebotina, 1988; Kulikov et al., 1990).

The researches on a soil-plant cover take a prominent place in the complex of works on the continental radioecology. In the group of general biospheric functions "the soil" plays a role of a habitat, an accumulator and a source of substance and energy for land organisms and a link in a biological and geological turnover (Dobrovolskiy, Nikitin, 2000). The soil-plant cover of the biosphere is the first screen from radioactive substances that enter the surface of the Earth from the atmosphere. The radionuclide exchange between the atmosphere and the hydrosphere proceeds through the soil-plant cover; and with the soils becoming the main deport of radionuclides in the land natural environment (because the secondary syntheses and destructions of a large number of substances of a biogenic origin as well as various biogeochemical and bioenergetic transformations proceed in the soils).

The development of nuclear power engineering implies a reduction in scales of using a fossil fuel. This is to decrease an air pollution due to a reduction of regular fallouts of soot, hard particles, oxides and microelements (deleterious for humans) into the atmosphere from thermal power stations and an elimination of dusty ash refuses, that makes needless to take oxygen from the atmosphere to burn the fossil fuel. At the same time a normal operation of a nuclear power plant produces gas-aerosols fallouts and liquid waste effluents that release some quantities of fission products of nuclear fuel (inert radioactive gases, ^{3}H, ^{90}Sr, ^{131}I, ^{134}Cs, ^{137}Cs, ^{144}Ce and etc.), induced-activity nuclides ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{60}Co, ^{65}Zn as well as natural and transuranium elements. Even the transfer of radioactive substances in controlled quantities to the environment of nuclear power sites leads to a formation of local zones with a higher content of radionuclides there (Delmas et. al., 1973; Ragsdale, Shure, 1973; Heine, Wiechen, 1977; Kulikov, Molchanova, 1981; Olsen et al., 1981; Aleksakhin, 1982; Molchanova et.al., 1985; Kulikov et al., 1990; Molchanova, Karavaeva, 2001).

Radioecological studies of natural ecosystems in the 30km zone of the Beloyarsk Nuclear Power Plant (BNPP) that works in a normal operation mode are being conducted since 1978. The studies of this kind are always a live issue, that is important because even a normal operation of NPPs can lead to a contamination of the environment. A radioactive contamination can be caused by both gas-aerosol fallouts into the atmosphere and industrial liquid waste effluents. Gas-aerosol fallouts from NPPs are formed in different production rooms. Gaseous radionuclides mainly and aerosol substances in a lesser degree pass into the atmosphere through a vent system. Radionuclides that fall from the atmosphere are kept by a soil-plant cover and accumulated in the upper horizons of the soil. The long-living radionuclides: ^{60}Co, ^{90}Sr, ^{137}Cs, $^{238-240}Pu$ and also a group of heavy natural elements from a number of those transferred to the external environment are of a great interest (Aleksakhin, Polikarpov, 1981; Kryshev, Ryazantsev, 2000).

The contribution made by the gas-aerosol fallouts and liquid radioactive waste effluents discharged from the BNPP at normal operation mode into the contamination of different components of natural ecosystems will be estimated in this paper.

Materials and methods

The BNPP is one of the large nuclear sites of the Ural region; it is located near the cities Ekaterinburg and Asbest. The first stage of the BNPP consisted of two Units, which were commissioned in 1964 and 1967.They reached their design output of 300 MW in 1969 and were removed from operation by 1989. The second stage of the BNPP is Unit 3 with the fast neutron reactor BN-600, which has been operating since 1980. In 2014 Unit 4 with the fast neutron reactor BN-800 is to be put in operation.

The physicogeographical zoning scheme of the Middle Urals describes the BNPP area as a flatly slacking region of the taiga area of the Ural plain – mountainous country. Its climate is absolutely continental with a long severe winter and a relatively short warm summer (Alisov, 1956). Average temperatures are: minus 17-18°C in January and plus 16-17°C in July. A return of cold weather is usual in spring and night frosts last till the end of spring. An annual amount of falls is about 450mm; most of it refers to a winter period. The largest height of a snow cover on unprotected areas is not more than 60cm. The prevailing winds are: western and south-western winds in winter and a north-western ones in summer.

The surroundings of the Beloyarsk Nuclear Power Plant are a plain with rare hills that is covered mostly with birch-and-pine forests mixed with aspen trees. The forests have traces of an anthropogenic impacts; a shrub layer is weakly or moderately developed there. An herb-and-shrub layer coverage makes 60 to 70%; a moss-lichen cover is weakly developed there. Brown forest soils are being formed on the crust of weathering of granite-gneisses at the watershed areas of the territory examined.

In the vicinity of the BNPP, 3km to the south of it, there is a town Zarechny with a population of about 30 thousand people. In order to estimate the contribution of gas-aerosol fallouts from the BNPP the soil-plant cover of the ecosystems located at different distances from the BNPP, with the account of the wind rose and main elements of a relief, have been investigated (Fig.1). Soils were sampled from full profile cuts of 0 to 5cm, layer by layer, up to a depth of 30 to 40cm with the account of the area and genetic horizons. An overground mass of plants was cut from a certain area in the close vicinity to the soil cuts.

The observation of the Beloyarsk Nuclear Power Plant zone was focused on the radioecological study of the Olkhovsk bog-river ecosystem, that intakes controlled discharges of low active waste waters from the BNPP and the effluents from the sewage system of Zarechny. This ecosystem is 5km to the south-east from the BNPP. It comprises the Olkhovsk bog, with adjacent swamped areas and the small river Olkhovka that is originating from the bog and discharging into the Pyshma River, which are a part of the large Ob'-Irtysh river system. The bog is connected with a 200-meter artificial channel, through which $10^6 m^3$ of discharged and sewage waste waters were delivered to the bog annually in 1980-1990. A total area of the bog is about $0.3 km^2$ (its length is 2.5km and width is 100m), its outflow to the Olkhovka River was $(3 - 8)\cdot 10^6 m^3$/year by measurements. On the average it was larger than the discharged water volume by a factor of 5. At present time the discharged water volume is substantially reduced and the stream from the bog is $2.9\cdot 10^6 m^3$/year. In the bog a water height reaches 0.5m with its lower part of 0.2m being a water suspension comprising rotten remnants of plants. There are peat, silt or peaty sediments of 1.0 to 1.5m capacity under the suspension. As a rule, they are formed on initially flooded soils. The bottom sediments of the Olkhovka and the Pyshma rivers mainly consist of sand and silt, they are essentially different in their granulometric composition. The silt cediments are rich in fractions of fine-grain (0.05 to 0.01mm) sand and silt, while the sand ones contain larger quantities of a middle and small sized (1.0 − 0.25mm) sand. The prevailing plants in the plant cover of the bog are: *Phragmites communis Trin, Typha latifolia L., Lemna minor L., Carex vesicaria L.* There is an abundance of mixed birch-and-aspen grassy forests on flood plains of the Olkhovka and the Pyshma as well as on the banks of the bog itself; the soils are brown forest, with indications of gleization, loamy on sand-silt drifts.

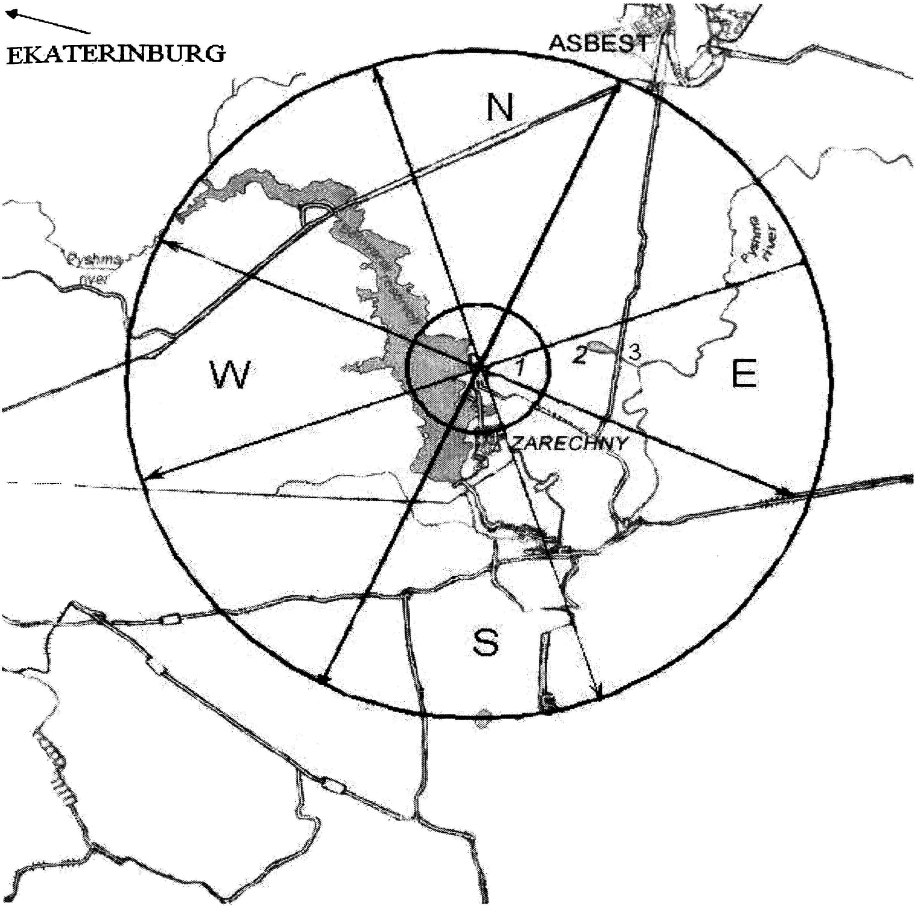

Figure 1. Schematic map of the Beloyarsk Nuclear Power Plant zone kept under observation. 1 – BNPP, 2 – Olkhovsk bog, 3 – Olkhovka River.

In the course of the research the sampling of the soils, dominant plant species and herbs was made in the Olkhovsk bog region. Water and bottom sediments were sampled directly in the discharge channel, the Olkhovsk bog, the Olkhovka River and also at the upstream and downstream from its mouth in the Pyshma River. Water samples volume of 40 liter were acidified to make pH 3 to 4 to prevent a sorption of radionuclides by the walls of vessels. At the territory of the bog four transects were embedded, they were located at different distances from the place of the waste-water discharge from the BNPP: at the inlet, in the middle part and at the outlet of the bog (Fig. 2). The bottom sediments were sampled within each transect with a pitch of 10m by layers of 25cm - capacity up to a depth of 125cm. For that a turf-prospecting auger was used.

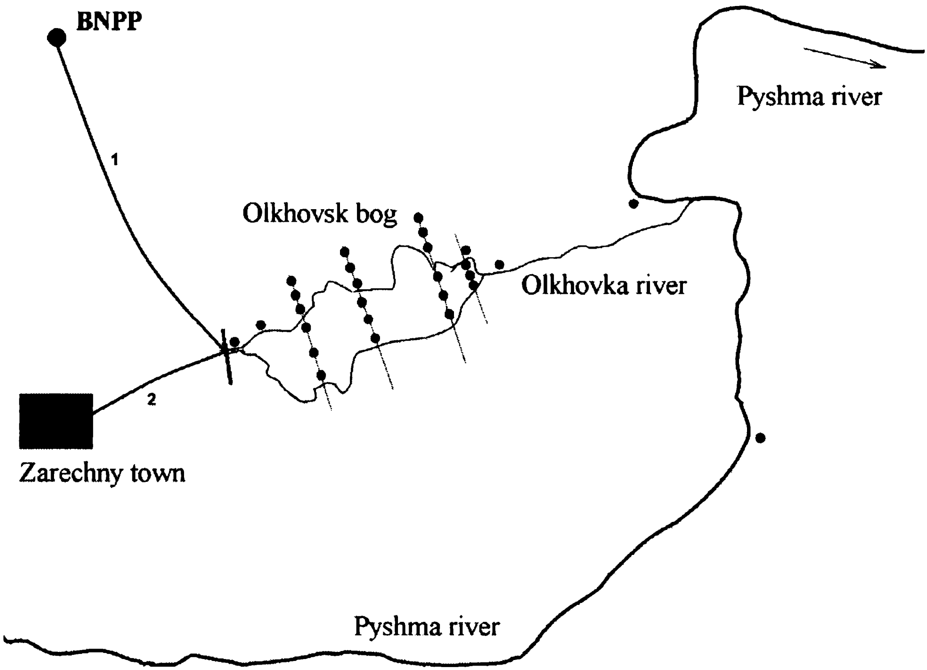

Figure 2. Schematic map of the Olkhovsk bog-river ecosystem; • – sampling; discharges: 1 – low active waste waters , 2 – sewage system of Zarechny.

The profile method was used to make soil cuts on the relief elements contiguous by flow off areas for the examination of the soil-plant cover adjacent to the bog. The profiles (500m long) embrace the watershed area of the left bank of the bog and lead through a gentle slope to the inlet, two transects in the middle part and the outlet the bog (Fig. 2). At the same time the observations were being made on a reference patch embedded outside the zone of BNPP influence. The reference patch comprises the watershed area, a slope's foot and a sphagnum-peat bog of high type.

The soil and sediment samples were dried to get air-dry condition, and then they were weighed, rubbed to powder and sieved through a 1mm-mesh. The samples of forest litters, organogenic horizons of soils and plants were dried. Water was filtrated to separate large suspensions and evaporated dry. All the samples were burn to ashes at a temperature of 450° to 500°C, and the ash was rubbed to powder.

The ^{137}Cs content in the prepared samples was determined with the multichannel gamma-analyzer with a germanium semiconductor detector ("Canberra Packard", USA) with a detection limit of 0.1 Bq. The ^{90}Sr content was determined by the radiochemical method. The procedures were based on the radionuclide leaching by 6N HCl – solution from preliminary prepared samples, precipitating of ^{90}Sr in the oxalate form and separating of ^{90}Sr kept in balance with the daughter product of decay – ^{90}Y (Pavlotskaya et. al., 1964; Tsvetaeva et. al., 1984). The measurement of a prepared specimen of ^{90}Y was carried out with the use of an alpha-beta radiometer (Russia), a detection limit of 0.2 Bq. Plutonium content in samples was also determined by the radiochemical method (Chen et al., 1993). This method includes leaching the isotopes of plutonium by a mixture of concentrated acids (HNO_3+HCl) from preliminary prepared samples, precipitating them on ion-exchange resin, then purifying and stripping from the ion-exchange column in succession by H_2O and 0.5N HNO_3 – solution, electrodepositing on disks made of stainless steel. The measurement of the prepared specimen was carried out with the use of spectrometer Alpha Analyst type of "Canberra Packard" (USA) with semiconductor detectors (PIPS) and software GENIE-2000. A lower detection limit was 0.001 Bq. Procedural error of the methods did not exceed 20%. A statistical measurement error with the instrumentation used was not more than 15%. The analytical data obtained underwent mathematical and statistical treatments. The resultant parameters were as follows:

Specific activity (SA) of radionuclides in the samples, Bq per unit mass or volume.

Contamination density or radionuclides stock in the soil profile, a radionuclide content in the examined part of the soil profile normalized to unit area, Bq/m^2

Integrated stock, a total content of a radionuclide in the components of a natural ecosystem of a certain territory, Bq.

Isotopic ratios, a ratio of content of isotopes of one chemical element in fallouts of nuclear fuel cycle enterprises and in objects of environment.

Radionuclide ratios, ratios of content of isotopes of different chemical elements in fallouts of nuclear fuel cycle enterprises and in objects of environment.

Results and discussion

1. Contributions of aerosol fallouts into a contamination of a soil-plant cover in the Beloyarsk Nuclear Power Plant zone.

At the first stages of monitoring of the soil-plant cover of terrestrial ecosystems in the BNPP zone, the levels of ^{90}Sr and ^{137}Cs content in the soil cover of plots of different types of ecosystems were estimated. The plots were located at different distances from the BNPP and with the account of four cardinal points and a landing direction of a fallouts torch. As it is seen from Table 1, the ^{137}Cs content in a layer of 0-20cm in the soils of the 30-km zone, as a rule, fluctuates around 3.0 to 4.0kBq/m^2 with the exclusion of the soils of forest communities and arable fields, located 5km to the south-east from the BNPP that are in the landing region of a fallouts torch. A density of ^{137}Cs contamination in these areas reaches 7.0 to 9.0kBq/m^2 A ^{90}Sr stock in the soil-plant cover practically does not depend on the locality of the areas examined. For forest phytocoenoses it varies from 1.0 to 1.5kBq/m^2, and for meadow and arable fields it varies from 0.5 to 1.3kBq/m^2 On the whole, the level of the radionuclide content in the soil-plant cover of the BNPP zone is within the limits of the background that was formed in the Middle Urals. A $^{90}Sr/^{137}Cs$ ratio value for the soil and plant cover changes from 0.10 to 0.52 and weakly correlates with the locality of the areas and the type of ecosystems.

The investigation of the plant cover in the 30-km zone of the Beloyarsk Nuclear Power Plant showed that the ^{90}Sr specific activity in the overground mass of the 14 representatives of flower plants changes from 3 to 16Bq/kg and practically does not depend on the family they belong to (Table 2). The ^{137}Cs specific activity varies in a wider range: from 5Bq/kg of *Matricaria recutita L.* to 190Bq/kg, *Potentilla argentea L.* A specific activity of spore plants is different: it is comparatively small for eatable mushrooms (55 – 80Bq/kg for ^{137}Cs and 11 – 13 Bq/kg for ^{90}Sr); and higher specific activity values are typical for moss and lichen (180 – 900Bq/kg for ^{137}Cs and 90 – 400Bq/kg for ^{90}Sr), though they are not higher than the values for the representatives of these groups of plants that grow in other regions of the country (Nifontova, Kulikov, 1977; 1981; 1983; 1984).

Table 1. A stock of radionuclides in the soil-plant cover of the natural ecosystems and arable fields located in the 30-km zone of the BNPP, kBq/m^2

Distance from BNPP, km	Sector	Ecosystem	^{90}Sr	^{137}Cs	^{90}Sr/ ^{137}Cs
0.5	North-East	Herbs-grasses meadow	0.7±0.1	4.0±1.0	0.17
		Mixed forest	1.0±0.2	4.3±1.2	0.23
3.0	South	Agrocoenoses	0.8±0.1	3.8±1.1	0.21
5.0	South-East	Herbs-grasses meadow	1.3±0.2	4.3±0.2	0.30
		Mixed forest	1.5±0.1	9.0±1.2	0.17
		Agrocoenoses	0.7±0.1	7.0±1.9	0.10
25.0	West	Herbs-grasses meadow	0.5±0.1	3.0±0.9	0.17
		Mixed forest	1.0±0.3	1.9±0.6	0.52
30.0	North	Mixed forest	0.9±0.3	3.3±1.3	0.28
400.0	South	Mixed forest*	1.1±0.3	4.5±1.0	0.24

*-control plots

In general the above data prove that gas-aerosol fallouts from the BNPP do not make an essential contribution to the ^{90}Sr and ^{137}Cs contamination of the terrestrial ecosystems adjacent to the BNPP. In 1980s annual radiation doses in the surroundings of the BNPP were estimated by using thermo-luminescent dosimeters, they showed that averaged dose values in the locality around the BNPP were 1.3mSv/year. In the most probable direction of a torch fall the annual average dose increases by 0.2mSv (Gotlib et. al., 1982). The results obtained from the researches conducted in the areas of Smolensk, Novovoronezh and Leningrad NPPs ("Radioactive contamination...", 1990; Nedbaevskaya et. al., 1991) proved the absence of a significant radioactive contamination of environment with gas-aerosol fallouts from NPPs operating in a normal mode.

Table 2. Specific activity of radionuclides in overground mass of plants, Bq/kg of air-dry mass

Species	^{90}Sr	^{137}Cs
Matricaria recutita L.	3±0.1	5±0.5
Tussilago farfara L.	6±1.6	23±4.3
Achillea millefolium L.	7±1.0	15±2.0
Taraxacum officinale Wigg	7±0.5	22±1.8
Tanacetum vulgare L.	16±0.6	24±1.8
Arctium tomentosum Mill.	5±0.5	8±0.2
Artemisia absinthium L.	4±0.4	14±2.0
Berteroa incana L.	10±2.0	17±2.0
Urtica dioica L.	12±0.3	130±10.5
Plantago major L.	4±0.4	10±0.1
Potentilla anserine L.	10±3.0	49±10.0
Potentilla argentea L.	8±1.5	190±26.0
Galium verum L.	10±1.0	87±8.0
Leonurus quinquelobatus Gilib.	5±1.0	17±2.0

Since 1988 the program of transition to MOX-fuel (mixed uranium – plutonium fuel) is being implemented at the operating BN-600 reactor at the Beloyarsk Nuclear Power Plant (Sarayev et. al., 2000). This fast reactor is also used for a "burning" of weapons-grade plutonium along with the plutonium fuel production. A plutonium stocks reduction is an important ecological problem. A usage of Pu as a component of nuclear fuel will increase with a commissioning of BNPP Unit 4 with the fast reactor BN-800. Taking into consideration these circumstances we carry out a radioecological monitoring of not only ^{90}Sr and ^{137}Cs but also $^{238-240}Pu$ at a present stage of the research conducted in the 30-km zone of the BNPP. An interest to the research of Pu content in natural environment is determined by a biological hazard from its isotopes as they have long half- lives (^{238}Pu – 87.74 years, ^{239}Pu – 24070 years and ^{240}Pu – 6580 years). Currently in the belt between 50°

and 60° northern latitude the integrated density of a soil-plant cover contamination with Pu isotopes due to global fallouts varies from 30 to 300Bq/m^2, and a value of isotopic ratio $^{238}Pu/^{239,240}Pu$ is from 0.02 to 0.03 ("Plutonium...", 2000). The results of the comprehensive radioecological examination of the soil cover in the 30-km zone of the BNPP are given in Table 3.

Table 3. A stock of ^{90}Sr, ^{137}Cs and $^{239,240}Pu$ in the soils of the 30-km zone of the Beloyarsk NPP, kBq/m^2

Distance from BNPP, km	Sector	Ecosystem	^{90}Sr	^{137}Cs	$^{239,240}Pu$
1.0	North-East	Mixed forest	1.0	6.1	0.054
1.5		Mixed forest	Not determined	4.3	0.041
5.0		Meadow	1.4	4.1	0.080
11.0		Mixed forest	1.3	5.3	0.023
28.0		Mixed forest	Not determined	5.1	0.050
		Average	1.2±0.2	5.0±0.4	0.035±0.010
1.0	South-East	Mixed forest	1.9	4.9	0.127
5.0		Mixed forest	0.6	2.0	0.113
7.0		Mixed forest	1.8	6.8	0.165
9.0		Mixed forest	0.9	2.4	0.024
10.0		Meadow	1.2	0.9	Not determined
		Average	1.3±0.2	3.4±0.9	0.107±0.40
10.0	West	Mixed forest	0.9	2.6	0.031
18.0		Mixed forest	0.8	2.2	0.025
27.0		Meadow	0.4	1.4	0.079
		Average	0.9±0.1	2.4±0.4	0.028±0.005

In the area of dedicated sectors that are oriented by the four cardinal points the radionuclide content changes by a factor 2 to 7 depending on the conditions formed in a biotope. However, the differences observed within the sectors are bigger than those between the sectors. This makes possible to calculate average values and estimate variation limits of the radionuclide content under study: 0.4 – 1.9kBq/m^2 of

^{90}Sr, 0.9 – 6.1kBq/m^2 of ^{137}Cs and 0.008 – 0.165kBq/m^2 of $^{239,240}Pu$. However densities of a soil cover contamination with ^{90}Sr and $^{239,240}Pu$ in the BNPP area do not differ from those for global fallouts in the belt between 50° and 60° northern latitude, but for ^{137}Cs they are higher though being within the limits of values typical for the Ural region.

Thus, almost a 50-year period of the BNPP operation did not lead to any increase in the content of ^{90}Sr and $^{239,240}Pu$ in the soil-plant cover of its 30-km zone. The increased density of the soil contamination with ^{137}Cs is not the result of the BNPP operation; it is rather the effect of the radioecological situation, which is forming in the Ural region.

2. A contribution of liquid radioactive waste effluents discharged from the Beloyarsk Nuclear Power Plant into a contamination of different components of natural ecosystems

A long-term discharge of low active waste waters from the NPP into the open natural ecosystem resulted in the formation of the zone with an increased content of radionuclides and the possibility of a contamination of adjacent territories (Karavaeva et.al., 1994; Karavaeva, Molchanova, 1995).

2.1. Radionuclides in the water and bottom sediments of the Olkhovsk bog-river ecosystem

Since a transfer of radioactive substances discharged to a bog-river ecosystem is made mainly with a liquid outflow the dynamics of the long-lived radionuclides in water of this system has been studied. From 1978 to 1986, when the Olkhovsk bog-river ecosystem was periodically affected by the operation of all the three BNPP Units, the specific activity of radionuclides on the length of "the discharge channel – the Olkhovka river mouth" was changing by a factor of ten within the years of observations (Fig.3).

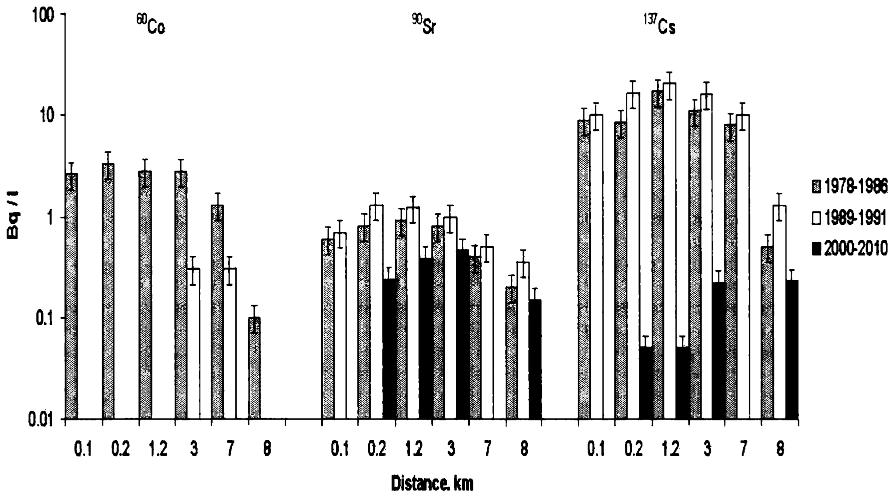

Figure 3. Specific activity of radionuclides in water of the Olkhovsk bog-river ecosystem in different years of observation.

In that time period the average specific activity values of ^{60}Co, ^{90}Sr и ^{137}Cs in water were 2.5; 0.7 and 15.6 Bq/l, respectively. They are approximately 20, 9 and 75 times higher than in water of the Pyshma River in the place ahead the Olkhovka falls into the Pyshma. Since 1989 after the decommissioning of the first stage (Unit I and Unit II) of the BNPP the delivery of ^{60}Co along with the liquid effluents was practically stopped and the "traces" of this radionuclide were detected only in the source and mouth of the Olkhovka River. The ^{90}Sr specific activity did not change essentially and the ^{137}Cs specific activity reduced in water of the bog-river ecosystem in the period from 1989 to 1991 as compared to the previous years of observations. In the course of time the radionuclide content continued to reduce. However, even in the period of 2000 to 2010 the actual (P = 0.05) increase in specific activity of ^{90}Sr and^{137}Cs was found in the downstream of the Pyshma as compared to water of the Pyshma in the place ahead the Olkhovka falls into it. That is the consequence of the radionuclide release from the Olkhovsk bog along with a river water outflow. Radionuclide content is more or less constant in water sampled along the vector of the outflow on the plot from the discharge channel to the mouth of the Olkhovka. That testifies that the emitters migrate without a substantial dilution. That was proved by the dispersion analysis that revealed the weak dependence of a specific activity of the radionuclides in water on the distance from the place of the waste water discharge (Table 4).

Table 4. Dependence of the specific activity of radionuclides in water against the place of sampling. Results of the dispersion analysis

Variations	Radionuclide	$F_{actual.}$	η_x^2, %	$F_{tabulated.}$		
				5%	1%	0.1%
On factor A	^{60}Co	2.3	18.6	2.6	3.8	5.7
	^{90}Sr	2.9	2.6	2.5	3.6	5.1
	^{137}Cs	4.2	5.6	2.5	3.5	5.0

Note. Factor A is the distance from the place of waste water discharge, η_x^2 is the indicator of a force of effect, F is the Fisher Criterion.

It was important to estimate a form (water-soluble or colloidal), in which the radionuclides migrate along with a liquid outflow, since a mobility of radionuclides in natural ecosystems is determined by their condition in a solution. The results of the research showed that the main part (87 – 99%) of ^{90}Sr and ^{137}Cs migrated with the liquid outflow in an actually diluted condition. A content of ^{90}Sr in a colloidal fraction is not more than 5 %, and that of ^{137}Cs is 12 %.

It is known that river earths and bottom sediments in basins are able to absorb and keep tight micro-quantities of chemical microelements, including radionuclides (Timofeeffa-Ressovskaya, 1963; Lyubimova, 1971; Safronova, Pitkyanen, 1973). Due to this fact a role of bottom sediments during a migration of ^{60}Co, ^{90}Sr and ^{137}Cs in a bog-river ecosystem has been studied. Studies of several years on bottom sediments sampled from the depth of 0 to 20cm at different distances from the discharge place of waste waters from the BNPP showed a high variability of radionuclides specific activity as dependent on the year of observations (Table 5).

Table 5. Specific activity of radionuclides in bottom sediments of bog-river ecosystem from 1978 to 1986, kBq/kg; (variation limits are in brackets)

Place of sampling	^{60}Co	^{90}Sr	^{137}Cs
Silt			
Discharge channel	5.0 (3.0 – 46.0)	0.20 (0.06 – 0.27)	22.0 (18.0 – 28.0)
Bog: beginning	34.0 (1.0 – 60.0)	1.80 (0.48 – 3.80)	58.0 (9.0 – 110.0)
middle part	30.0 (1.0 – 7.0)	1.20 (0.07 – 3.40)	27.0 (7.2 – 65.0)
Olkhovka River:			
source	1.40 (0.77 – 2.30)	0.19 (0.60 – 0.87)	30.0 (8.0 – 51.0)
mouth	0.90 (0.15 – 2.10)	0.14 (0.01 – 0.24)	34.0 (7.0 – 86.0)
Pyshma River:			
upstream	0.05 (0.02 – 0.08)	<0.01	0.37 (0.10 – 0.97)
downstream	0.03 (0.01 – 0.07)	<0.01	3.00 (0.15 – 3.90)
Sand			
Discharge channel	4.0 (1.6 – 6.0)	0.07 (0.02 – 0.10)	16.0 (7.0 – 25.0)
Olkhovka River:			
source	0.20 (0.10 – 0.15)	0.03 (0.02 – 0.15)	20.0 (10.0 – 30.0)
mouth	0.30 (0.14 – 0.50)	0.06 (0.01 – 0.17)	16.0 (3.0 – 26.0)
Pyshma River:			
upstream	0.04 (0.01 – 0.10)	<0.01	0.09 (0.03 – 0.20)
downstream	0.03 (0.01 – 0.10)	<0.01	0.21 (0.15 – 0.33)

The main contaminator of bottom sediments in the area of bog- river ecosystem from the waste water discharge place to the Olkhovka mouth is ^{137}Cs, followed by ^{60}Co and ^{90}Sr in the order of decreasing. As a rule, specific activity values of these radionuclides in bottom sediments are tens of kBq/kg for ^{137}Cs, units of kBq/kg for ^{60}Co and tenth to hundredth fractions of kBq/kg for ^{90}Sr. Maximum specific activity (^{60}Co – 60; ^{90}Sr – 4 and ^{137}Cs – 110kBq/kg) is found in silts, that are forming at the beginning of the bog, in the contact place of the bog and discharge waters. The content of all the three contaminators in the Pyshma bottom sediments reduces by one or two orders of magnitude, the content in sand sediments being less than in silts. A noticeable increase of ^{137}Cs content in bottom sediments was detected in the downstream of the Pyshma River.

After decommissioning of the first stage of the BNPP the content of ^{60}Co and ^{90}Sr in the bottom sediments of the Olkhovsk bog and earths of the Olkhovka River was 0.01 and 0.1kBq/kg, respectively; by the year 2000 it was at the detection limit. ^{137}Cs (though still being the main contaminator of the bog-river ecosystem) reduced its content in the bottom sediments and it did not exceed 15kBq/kg by the year 2000 (Table 6).

Table 6. ^{137}Cs in bottom sediments of the bog-river ecosystem, kBq/kg

Place of sampling	Bottom sediments	Years of sampling		
		1989	1994	2000
Discharge channel	Sand	14.0±2.8		
	Silt	29.8±3.5	8.5±0.8	3.2±0.9
Bog: beginning	Silt	64.7±5.4	4.5±0.3	15.4±5.1
middle part	Silt	26.7±10.0	10.0±0.1	
The Olkhovka River:				
source	Sand	18.8± 7.1	11.7±0.5	
	Silt	36.2± 6.7	19.1±1.6	4.5±1.0
mouth	Sand	18.9± 2.0	7.0±0.1	
	Silt	27.8±11.2	9.4±2.9	14.0±3.0
The Pyshma River:				
upstream	Sand	0.2±0.02	0.05±0.001	0.04±0.01
	Silt	1.2±0.08	0.07±0.008	0.12±0.01
downstream	Sand	0.8±0.07	0.20±0.01	0.20±0.01
	Silt	6.4±0.90	1.3±0.04	1.10±0.35

The study of the vertical distribution of radionuclides in depth of the bottom sediments showed that maximum specific activity values correspond to the upper 25cm-layer of the bottom sediments in the bog (Fig. 4).

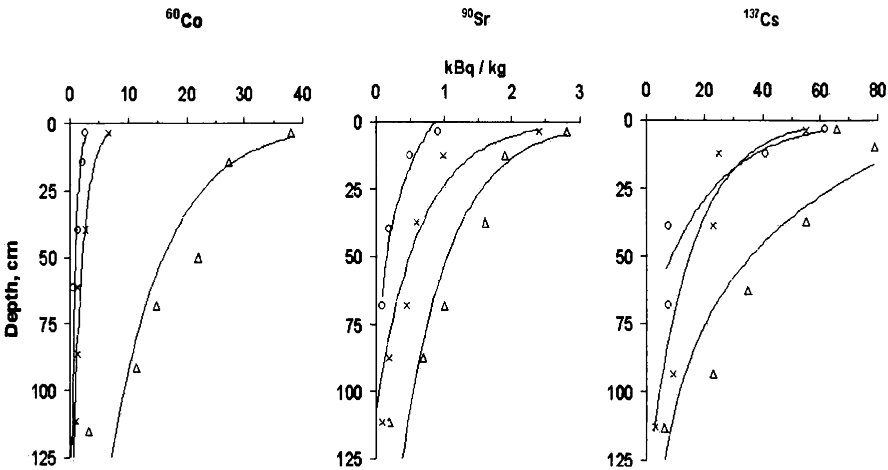

Figure 4. Specific activity of radionuclides in the bottom sediments of the Olkhovsk bog. Plots: ○ – the beginning; x – the middle; Δ –the end of the bog

In accordance with the differences in the specific weight of bottom sediments the main content of emitters is concentrated in the layer of 50cm capacity, which is in the direct contact with the discharge water flowing through the bog (Table 7). In addition to the above radionuclides, the content of plutonium isotopes ($^{238\text{-}240}Pu$) in deposited components of the Olkhovsk bog-river ecosystem is being estimated since 1999, because the Pu isotopes can enter this system together with liquid effluents during operation of all the three BNPP Units. For the estimates the isotopic ratio method was used, that permitted to determine the contribution of any source into a contamination of environmental components. The research results obtained show that the specific activity of ^{238}Pu in the upper 0 – 5cm layer of the bottom sediments does not depend on the place of sampling; the same is true for $^{239,240}Pu$ (Table

8). The specific activity varies within the limits of 0.1 to 8.9 for ^{238}Pu and 0.7 to 12.7Bq/kg for $^{239,240}Pu$, and a value of the ratio $^{238}Pu/^{239,240}Pu$ is 0.40 to 0.76 in the average. In the bottom sediments of the Olkhovka River and the Pyshma River (7km from the waste water discharge place) the specific activities of plutonium isotopes keep approximately the same level, which is somewhat lower than that in the Olkhovsk bog. At the rest area of the Pyshma River (8 – 35km from the waste water discharge place) the content of plutonium isotopes reaches minimum values, and a value of the ratio $^{238}Pu/^{239,240}Pu$ reduces to 0.04. The earlier studies of the samples of the bottom sediments of the Pyshma River outside the BNPP influence (5km upstream from the mouth of the Olkhovka River show that the content of ^{238}Pu and $^{239,240}Pu$ in them is not more than 0.2Bq/kg. A comparison of this value with the data in Table 8 reveals that only at the distance of 8-35km from the source of contamination the content of Pu isotopes in the bottom sediments of the Pyshma River does not differ, and in all the rest cases it is reliably higher than the control level.

Table 7. Radionuclides distribution in depth of bottom sediments of the Olkhovsk bog, %

Place of sampling	Radionuclide	Depth of sampling, cm				
		0 – 25	25 – 50	50 – 75	75 – 100	100 – 125
The beginning of the bog	^{60}Co	33	25	19	13	10
	^{90}Sr	35	24	20	12	9
	^{137}Cs	25	31	21	13	10
The middle of the bog	^{60}Co	57	22	5	9	7
	^{90}Sr	55	20	13	7	5
	^{137}Cs	44	20	19	10	7
The end of the bog	^{60}Co	54	19	15	12	
	^{90}Sr	49	22	16	11	2
	^{137}Cs	37	27	19	14	3

Table 8. Plutonium isotopes in 0-5cm layer of bottom sediments of the Olkhovsk bog- river ecosystem and the Pyshma river (Minimum and maximum data are in brackets)

Place of sampling	Distance to the waste-waters discharge, km	^{238}Pu, Bq/kg	^{239,240}Pu, Bq/kg	^{238}Pu/ ^{239,240}Pu
Olkhovsk bog	0.2	4.5(0.7 - 8.9)	6.0(0.7 - 12.7)	0.76
	1.2	0.7(0.1 - 0.9)	1.7(0.9 - 2.0)	0.40
	2.5	3.3(0.9 - 8.9)	4.9(1.3 - 12.0)	0.72
Olkhovka River:				
source	3.0	0.8(<0.1 -1.2)	1.3(0.8 - 1.8)	0.42
upper stream	3.5	0.2(0.1 - 0.2)	0.5(0.4 - 0.6)	0.40
Pyshma River, downstream	7.0	0.4(<0.1 - 0.8)	1.2(0.1 - 2.3)	0.38
	8.0 - 35.0	<0.1	0.1(<0.1 - 0.2)	0.04

The peculiarities of the vertical distribution of ^{239,240}Pu (Table 9) were investigated with a consideration of the higher content of plutonium isotopes in the Olkhovsk bog bottom sediments and their high water content. In peaty deposits and bog soils significant (23.9 – 32.0 %) amounts of ^{239,240}Pu were found at a depth of 20cm. In silt sediments up to 89% radionuclide is concentrated in 0 – 5cm layer. Silt sediments are rich in ^{239,240}Pu to a greater extent than the peaty ones and bog soils.

Thus, a long-term discharge of waste waters from the BNPP into the bog-river ecosystem resulted in the increase of the content of ^{60}Co, ^{90}Sr and ^{137}Cs in water and the accumulation of the radionuclides in the bottom sediments of the bog. It is obtained by a calculation that the stock of radionuclides (mainly ^{137}Cs) in the Olkhovsk bog is about $3.7 \cdot 10^{12}$Bq at present time; and the main quantity of the radionuclides (99%) is in the bottom sediments. This fact makes the Olkhovsk bog to be a potential source of contamination of the contiguous territories and the open hydrographic network.

Table 9. Vertical distribution of $^{239,240}Pu$ in bottom sediments and soils of the bank zone of the Olkhovsk bog.

Sample	Depth, cm	Bq/m^2	%
Bottom sediments: Peaty	0 – 5	15.2	14.7
	5 – 10	45.0	43.5
	10 – 15	18.6	18.0
	15 – 20	24.7	23.9
	Total	103.5	100
Silt	0 – 5	252.2	89.2
	5 –10	28.2	10.8
	Total	280.4	100
Bog soil	0 –5	9.7	16.3
	5 –10	8.4	14.1
	10 – 15	13.4	22.5
	15 –20	19.0	31.9
	20 – 25	9.0	15.2
	Total	59.5	100

2.2. Distribution of radionuclides in the soils of the areas adjacent to the Olkhovsk bog-river ecosystem

The results of the examination of the soil cover of the areas contiguous by flow off and adjacent to the bog are shown in Table 10. In the soils of the watershed and the middle of the slope the ^{60}Co specific activity is lower than the sensitivity limit of the detection method used. Only in the areas of the near-bog soils this radionuclide is found in the layer of a forest litter and upper horizon at the depth of not more than 6cm.

The soils of the watershed, slope's middle and bog's bank are characterized practically by the same specific activity values of ^{90}Sr. The detailed analysis of the material available permits to note a tendency to an increase of ^{90}Sr content (Bq/m^2) in plants, growing on the periodically flooded banks of the bog, fall and upper layer of the well-decayed matter of a forest litter of 1cm capacity:

Sample	Watershed	Bog bank
Herbs	25±2	66±20
Fall	50±5	98±20
Forest litter	89±14	157±18

Table 10. Radionuclides in the soils of contiguous landscape areas, Bq/kg

Soil	Depth, cm	^{60}Co	^{90}Sr	^{137}Cs
Brown forest (watershed)	0 – 1	b.d.l.*	52±5	200±30
	1 – 5	<<	30±4	215±67
	5 – 10	<<	7±3	25±11
	10 – 15	<<	3±1	b.d.l.
Soddy-meadow (slope's middle)	0 – 1	<<	70±10	230±20
	1 – 2	<<	90±27	170±7
	2 – 7	<<	39±10	82±5
	7 – 12	<<	6±3	25±8
Brown forest, gleization (bog's bank)	0 – 1	290±150	40±10	5110±185
	1 – 6	125±20	28±5	3440±175
	6 – 11	b.d.l.	13±4	280±30
	11 – 16	<<	3±1	b.d.l.

* -below the detection limit

The specific activity of ^{137}Cs in the profile of soils at the boundary of the Olkhovsk bog is by a factor of 10 to 20 higher than that in the areas at the distance of 0.5 – 1.0km from it (watershed, slope's middle). A higher content of ^{137}Cs in the soils near the bog is explained by additional delivery of the radionuclide together with the contaminated water when bog-side areas are flooded periodically. In all the cases the forest litter (0 – 1cm) and upper (1 – 5cm) layer of the soil are characterized by maximum specific activity values of the radionuclides. The attention is drawn to a small speed of a vertical migration of the radionuclides in the soils examined. A detailed study of a soil layer, 10cm thick, shows that the concentration of ^{90}Sr and ^{137}Cs in the soils of geochemical contiguous are monotonously decreasing with depth (Table 11). Their accumulation prevails in a forest litter (0 – 1cm) and soil layers up to a level of 3 to 4cm. The noted layers being the upper, most rich in humus part of the accumulative horizon, intercept and transform the radionuclides, coming to the soil cover from a plant fall along with atmospheric and surface waters. As the first barrier to their migration way they can be the indicators of the radionuclide contamination of soils.

Table 11. Distribution of radionuclides in a 0-10 cm layer of the soils of geochemical contiguous, Bq/kg

Horizon, depth,cm	^{90}Sr			^{137}Cs		
	Watershed	Slope's middle	Bog's bank	Watershed	Slope's middle	Bog's bank
A_0 0-1	78	70	80	190	230	3550
A 1-2	160	60	170	260	200	3900
2-3	64	120	80	470	140	2500
3-4	30	100	75	380	190	600
4-5	22	40	24	70	60	590
5-7	10	10	15	40	40	525
7-10	8	5	8	60	40	290

The mathematical treatment of the data from Table 11 shows (Fig.5) that a distribution of the specific activity of ^{90}Sr and ^{137}Cs in depth of the soils in the region of the Olkhovsk bog is well approximated by the sum of exponents:

$$C_{(x)} = \sum_{i=1}^{N} C_{i0} \exp\left(-\frac{(x - x_{i0})^2}{a_i}\right),$$

where I – the number of exponents, that describe the distribution curve;

x_{i0} – the depth (cm), at which the i-th term of the sum has a maximum value C_{i0} (Bq/kg);

a_i – the parameter of the curve, cm^2

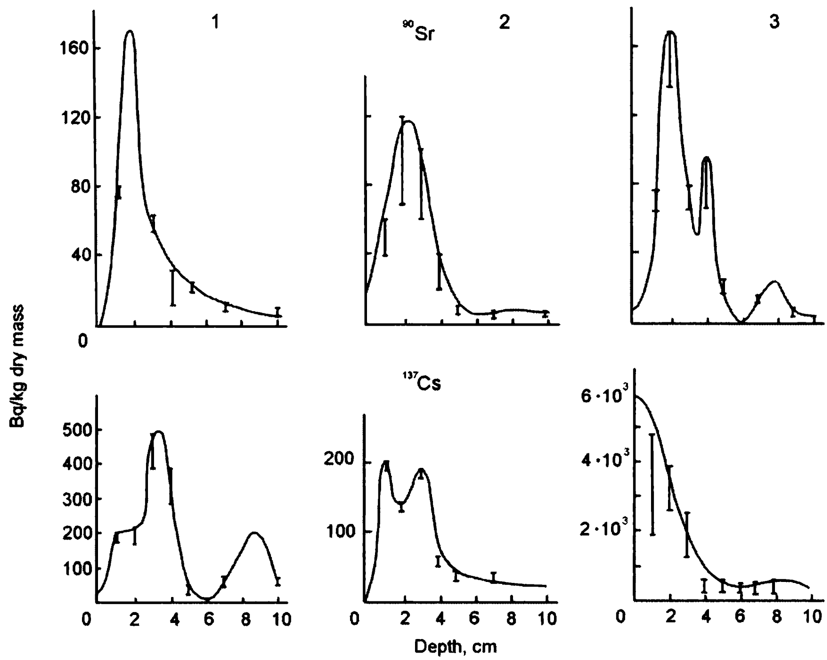

Figure 5. Distribution of radionuclides in depth of soils. 1 – watershed; 2 – slope's middle; 3 – bog's bank.

It follows from data on the empirical constants in Table 12 that the value of $C_{(x)}$ is made of two or three exponents. Their number can be related to the different strength of fixing the radionuclides in the soils and, consequently to the different speed of the vertical movement. The deviations to a larger depth of maximum values of specific activity of ^{90}Sr as compared to ^{137}Cs are noticed at the watershed and slope's middle. For the near – bog soils subjected to temporary flooding the distribution of ^{90}Sr reveals two maxima : the first one corresponds to the surface layer of 1 to 2cm and the second one corresponds to the depth of 3 to 4cm.

Table 12. Empirical constants of the distribution curve of radionuclides specific activity in depth of a soil layer

Constants	Watershed			Slope's middle			Bog's edge		
I	1	2	3	1	2	3	1	2	3
x_{i0}	1.80* / 1.50	3.60 / 3.40	6.50 / 8.70	2.30 / 1.00	9.00 / 2.70	– / 6.20	2.00 / 0.00	4.15 / 7.50	7.80 / –
C_{i0}	170 / 250	332 / 500	114 / 2200	120 / 170	7 / 190	– / 40	170 / 6000	90 / 600	25 / –
a_i	0.8 / 1.0	1.6 / 1.0	8.0 / 1.6	2.8 / 0.2	5.6 / 1.4	– / 16.8	1.2 / 8.0	0.4 / 8.0	1.2 / –

*Asterisk over the line is for ^{90}Sr and that under the line is for ^{137}Cs.

The radionuclide stock in a 0 – 10cm layer of soils was estimated with the account of a bulk weight (Table 13). The stock of ^{90}Sr was approximately the same in the soils of the control plots and in the soils of the Olkhovsk bog region. It is practically the same also for the soil-plant cover of eluvium and accumulative areas of landscape.

Table 13. Stock of radionuclides in a 0 – 10cm layer of soils of the Olkhovsk bog region (1) and in the control plots (2), kBq/m^2

Place of sampling	^{90}Sr		^{137}Cs		$^{137}Cs/^{90}Sr$	
	1	2	1	2	1	2
Watershed	2.2±0.1	1.5±0.2	9.3±1.2	6.8±0.5	4.2	4.5
Slope's middle	1.3±0.2	1.2±0.1	4.3±0.2	4.9±0.6	3.3	4.0
Bog's bank	1.9±0.5	1.2±0.1	63.7±9.7	4.9±0.4	33.5	4.1

At the areas bordering the bog the stock of ^{137}Cs is approximately an order magnitude higher than in the control plots In the control plots of soils the content of ^{137}Cs is by a factor of 4 higher than that of ^{90}Sr, and in soils adjacent to the bog this ratio is equal to 33.5. The increase of ^{137}Cs content in near- bog soils, which are fed by both the surface and the ground waters, is rather due to the receipt of water from the Olkhovsk bog than due to the migration of radionuclides from the landscape areas located higher and contiguous along the surface and water flow.

The accident at the Chernobyl NPP caused the contamination of several regions of Russia. In order to estimate a deleterious effect of this accident on a contamination of the soil-plant cover in the Beloyrsk NPP area in May 1986 the sampling of a plant fall and upper (0 – 5cm) layer of the soil was made in the assumption that fresh radioactive fallouts had not penetrated to a large depth. The samples were taken from a mixed forest (the watershed) and an open meadow (the slope's middle) within the limits of the geochemical profile leading to the middle part of the Olkhovsk bog. As it was said above, the soils in these areas were not directly affected by the contaminated waters of the bog. The analysis of the results obtained revealed a double and triple increase in the specific activity of ^{90}Sr in the plant fall in both areas (Table 14).

It was exactly the plant fall as a natural plane table that was impacted first by the radioactive contamination in the early spring of 1986 before the time of formation of leaves and a grass cover. The true increase in ^{90}Sr content in soil layers was not found in the year of the Chernobyl accident. In the following years, at the background of a decreasing specific activity of ^{90}Sr in the fall, it increased noticeably in the forest soil layer of thickness 2-5cm. The ^{137}Cs specific activity in the forest fall in 1986 increased 35 times and in the plant cover of the meadow it increased 65 times as compared to the mean multi-year values. These results are of an interest regarding the Fukusima-1 accident in Japan in 2011 and with a focus on the necessity of monitoring studies in the regions of potentially hazardous nuclear sites.

The usage of nuclear fuel rich-in uranium in the NPP process cycle is a potential possibility of additional receipt of a group of natural heavy radionuclides by the environment. Because of that the content of ^{226}Ra, ^{232}Th and ^{238}U was determined in the main components of the soil-plant cover adjacent to the Olkhovsk bog. Minimum specific activities of these elements were noted for the plants and a weakly-decayed fall matter. The specific activities of ^{232}Th and ^{238}U make tenth fractions, and that of ^{226}Ra is equal to units of Bq/kg of dry mass.

Table 14. Radionuclides in the soils of the Olkhovsk bog region at different periods of research, Bq/kg

Soil; place of sampling	Depth,cm	A year of sampling					
		^{90}Sr			^{137}Cs		
		1978-1985	1986	1989	1978-1985	1986	1989
Brown forest; watershed	Plant fall	70	140	85	180	6500	450
	0 – 1	78	100	120	190	2400	870
	1 – 2	160	100	150	260	1100	830
	2 – 3	64	80	190	470	400	940
	3 – 4	30	30	125	380	200	590
	4 – 5	22	25	110	40	35	300
Soddy-meadow; slope's middle	Plant fall	70	230	100	230	15000	180
	0 – 1	60	20	75	200	1900	400
	1 – 2	120	30	55	140	200	400
	2 – 3	100	20	35	90	100	230
	3 – 4	40	6	25	60	200	130
	4 – 5	10	10	15	40	80	80

In most cases the content of natural radionuclides in soil increases an order of magnitudes and reaches for ^{226}Ra – 25, ^{232}Th – 17, for ^{238}U – 14 Bq/kg, that does not exceed the corresponding values typical for different geographical zones (Vinogradov, 1957; Titaeva, Taskaev, 1983). The specific activity of natural radionuclides in plants and a soil as well as a manner of their distribution in depth of soil profile are practically the same for different areas of geochemical contiguous.

The study of a landscape migration of ^{90}Sr, ^{137}Cs and $^{238-240}Pu$ was carried out within the limits of a geochemical profile that comprised the bog, its bank zone in the region of the Olkhovka source and a contiguous watershed area. In this part of the bog the peaty deposits have formed; the bog soil prevails in the soil cover of the bank zone, which changes for brown forest soils with a distance from the bog. The results of the study showed that the bottom sediments contained ^{90}Sr and ^{137}Cs in the quantities by 1 – 2 orders of magnitude higher than the level of background values (Fig.6).

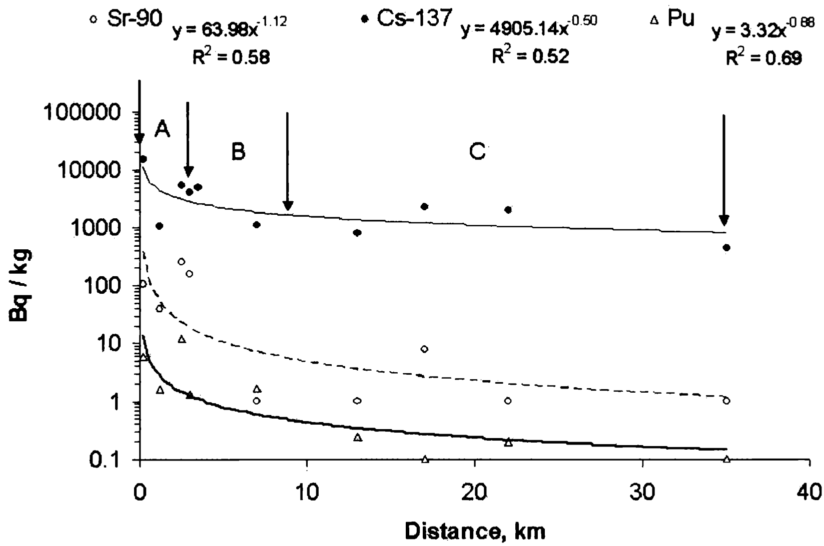

Figure 6. Radionuclides in bottom sediments of the Olkhovsk bog (A), the Olkhovka River (B) and the Pyshma River (C).

In the Pyshma river (7 km) the radionuclide content regularly decreases along the vector of the flow off and at the distance of 35km from the contamination source it keeps 5 to 10 times higher than the background for ^{137}Cs and does not exceed this value for ^{90}Sr. A plutonium scattering halo is within the confines of the bog; its maximum specific activity in the bottom sediments is 10 to 15Bk/kg. It is worth noting that outside of the effect of the BNPP liquid discharges, the radionuclide concentration in the bottom sediments of the Pyshma River (upstream from the source of the Olkhovka River) keeps at the level of 30 to 200Bq/kg for ^{137}Cs, 10Bq/kg for ^{90}Sr and 0.2Bq/kg for Pu. The comparison of these values with the data obtained for the final test point (35km) shows that the content of ^{137}Cs solely (the main contaminator of the Olkhovsk bog) is in the average by a factor of 10 higher than the background value.

In the detailed examination of the soil cover, adjacent to the bog, the content of Pu in the near-bog soils was estimated. The data obtained permitted to compare the average specific activity and the plutonium stocks in a 0-40cm layer of the bottom sediments and soils located at different distanced from the bank edge (Table 15).

Table 15. Specific activity and Pu stocks in a 0-40cm layer of bottom sediments of the Olkhovsk bog and soils of adjacent areas

Place of sampling	Object of research	Distance from the bog's bank, m	Pu		$^{238}Pu/^{239,240}Pu$
			Bq/kg	Bq/m^2	
Olkhovsk bog	Bottom sediments:				
	Peaty	–	2.5	140	0.37
	Silt	–	9.2	489	0.74
Flooded bank zone	Bog soil	7	1.1	99	0.63
		25	1.5	132	0.07
Unflooded bank zone	Brown forest soil	500	0.9	113	0.03

The analysis of the data did not reveal any essential differences in the specific activity and the stock of Pu in the soils versus the distance from the bog location. For the bog's bank soils (both flooded and unflooded) the Pu specific activity is not more than 1.5 Bq/kg and its total stock per unit –area does not differ from its global level. At the same time the isotopic ratio $^{238}Pu/^{239,240}Pu$ decreases with the distance from the bog and at a distance of 500m from it (unflooded bank zone) its value is 0.03.

It was of interest to examine in more details the hydromorphic soils adjacent to the Olkhovsk bog and determine not only the specific activity but also a plutonium stock. The detailed radioecological examination of hydromorphic soils at different distance from the BNPP waste water discharge shows that in an area length of 7 km, including the north bank of the bog, the flood plain of the Olkhovka and partially that of the Pyshma, the Pu stock varies from 98 to 166Bq/m^2 (Fig. 7). At the final test point (17km from the contamination source) it keeps at a level of 20Bq/m^2 The results obtained (R^2 = 0.726) are well approximated with an exponential function. Though the above values keep within the range of global background variations, the soil cover adjacent to the Olkhovsk bog and the Olkhovka River, is contaminated to a greater extent.

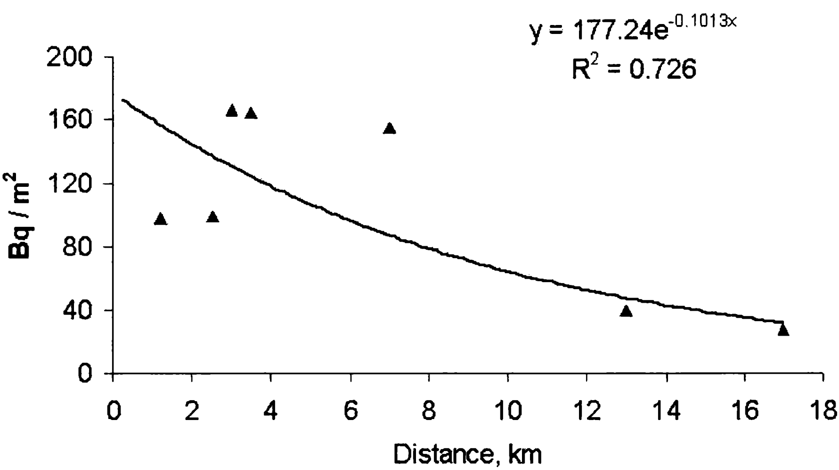

Figure 7. Density of hydromorphic soils contamination with Pu.

On the whole, the above data show that at the outlet of the bog (where the source of the Olkhovka River is formed) the specific activity of the radionuclides in the depot components of the ecosystem, stays at a relatively high level.

2.3. An estimate of scale release of radionuclides from the Olkhovsk bog

In order to estimate a scale of the radionuclides release from the bog into the open hydrographic network a special research has been carried out in the Olkhovka source in the periods of a spring flooding and a summer low level of water. According to the data from the literature and the measurement data obtained by the authors the water rate in the Olkhovka source during the spring flooding and the summer low water level period is 0.3 and 0.04m^3/sec, respectively. A maximum value of a hard runoff is 23g/sec was noted during the spring flooding and in the summer period it decreases to 1g/sec. As it is seen from Table 16, the specific activity of Pu in water of the Olkhovka during both periods is not more than 0.001Bq/l, and in the hard runoff it changes from 1.5Bq/kg during the flooding to 17.1Bq/kg in the summer period. For ^{90}Sr an increase of specific activity is observed for liquid and hard runoff of the river during the summer low water level in the river. The main contaminator of the Olkhovsk bog - ^{137}Cs, is characterized by a strong fixing in the suspension material; it enriches the fine dispersion fractions of the hard runoff in the flooding period.

Table 16. Content of radionuclides in the components of the river runoff

Radionuclide	Liquid runoff, Bq/l		Hard runoff, Bq/kg	
	Spring flooding	Summer low level of water	Spring flooding	Summer low level of water
$^{238-240}Pu$	0.001	0.001	1.5	17.1
^{90}Sr	0.25	0.87	206	790
^{137}Cs	0.60	0.10	5460	1420

As based on the available runoff parameters and the specific activity of radionuclides in the runoff components an annual departure of the radionuclides from the Olkhovsk bog was calculated (Table 17).

Table 17. Release of the radionuclides from the Olkhovsk bog

Radionuclide	Liquid runoff, %		Hard runoff, %		Total $n \cdot 10^6$ Bq/year
	Spring flooding	Summer low level of water	Spring flooding	Summer low level of water	
$^{238-240}Pu$	98.5	99.4	1.5	0.6	2.1
^{90}Sr	93.3	99.7	6.7	0.3	1169.0
^{137}Cs	57.1	80.0	42.9	20.0	1581.0

Irrespective of the season of a year approximately 99% Pu and 93-99% ^{90}Sr release along with the liquid component. The ^{137}Cs departure with the liquid stream is substantially less during the flooding period and it increases to 80% during the summer period, ^{137}Cs being distributed more or less uniformly in the runoff components during a spring flooding period. In the summer low level of water in the river, (when water deliberates from suspension), it transfers mainly being in a water-soluble condition. The annual release of the radionuclide amount from the Olkhovsk bog into the open hydrographic network is arranged in the following sequence: $^{137}Cs > ^{90}Sr > Pu$.

2.4. A contribution of different sources into a contamination of the environmental components with plutonium

It is known that the contribution of different sources into the contamination of environmental components with plutonium isotopes can be estimated by the value of the isotopic ratio $^{238}Pu/^{239,240}Pu$ (Aarkrog et. al., 1992; 1997; Mikhailovskaya et.al., 2007). It equals to 0.02 – 0.03 in the global fallouts from the atmosphere. As for the discharges from the BNPP this value was determined as based on the isotope concentration measurements of several years, which were made in the bottom sediments at the beginning of the Olkhovsk bog, directly close to the place of the receipt of the liquid effluents, its average value was 0.8 (Mikhailovskaya et.al., 2002). In the assumption that the contamination of the area under examination in the region of the Olkhovsk bog was formed as a result of the receipt of the global fall outs and liquid effluents discharged from the BNPP, the contributed amount from each of the sources can be calculated from the equation:

$\mathbf{K_1(A\text{-}x) + K_2x = K_3A}$, where

A – $^{239,240}Pu$ in the samples taken from the area examined, Bq/m^2;

x – $^{239,240}Pu$, received along with the liquid effluents discharged from the BNPP, Bq/m^2;

(A-x) – $^{239,240}Pu$ from the global fallouts, Bq/m^2;

$\mathbf{K_1, K_2, K_3}$ – the values of isotope ratio $^{238}Pu/^{239,240}Pu$ determined from the global fallouts, liquid effluents discharged from the BNPP and samples of the area examined, respectively.

It follows from the data obtained (Table 18) that in the area covering the bog, the Olkhovka River flowing out of it, and a small length of the Pyshma River (7 – 8km from the place of discharge from the BNPP) the value of the ratio $^{238}Pu/^{239,240}Pu$ keeps at a level of 0.40 to 0.76. In accordance with this, the BNPP contribution into the contamination of the bottom sediments is 61.4 to 96.6%.

The BNPP contribution was not detected outside the area mentioned above, along the vector of the runoff of the Pyshma River. Since the Olkhovsk bog is also the source of plutonium received by the contiguous soil cover, the BNPP contribution into the contamination of bottom sediments and soils (Table 19) was estimated. A maximum BNPP contribution was found in the silt sediments and bog soil in the direct vicinity of the bog.

Table 18. BNPP contribution into the plutonium contamination of the bottom sediments of the Olkhovsk bog – river ecosystem and the Pyshma River

Place of sampling	Distance from the waste water discharge place, km	$^{238}Pu/^{239,240}Pu$	Contribution from the BNPP, %
Olkhovsk bog	0.2 1.2 2.5	0.76 0.40 0.72	96.6 62.9 92.1
Olkhovka River	3.0 3.5	0.42 0.40	62.2 61.4
Pyshma River, downstream	7.0 8.0 – 35.0	0.38 0.04	53.1 Not detected

Thus, the gas-aerosol fallouts from the BNPP after a long-term operation in a normal mode have not led to expressed negative effects. At the same time as a result of a long-term discharge of low-active waste-water into the bog-river ecosystem there formed the zone, that is characterized by a higher content of radionuclides in all the components examined. The main contaminator of them is ^{137}Cs. This radionuclide in substantial amounts, sometimes exceeding the global levels two orders of magnitude, was found not only in the bottom sediments of the Olkhovsk bog but also in the soil-plant cover adjacent to it. The comparison of the isotope ratio $^{238}Pu/^{239,240}Pu$ values of the global fallouts, bottom sediments and near – bog soils testifies to the contribution of the liquid effluents discharged from the BNPP into their contamination with man-made plutonium. A quantitative estimation of this contribution shows that it reaches maximum values for silt bottom sediments of the bog (95.6%), then reduces to 88.4% with a transfer to the near – bog soils and practically is not detected in the soils at a distance of 50m from the bog's bank. In the bottom sediments of the open hydro graphic system linked with the bog by the water stream, the contribution from the BNPP is traced at a distance of 7km from the waste-water discharge and varies from 53.1 to 62.2 %.

Table 19. The BNPP contribution into the plutonium contamination of bottom sediments of different types of the Olkhovsk bog and contiguous soils.

Place of sampling	Object of research	$^{238}Pu/^{239,240}Pu$	Contribution from the BNPP, %
Olkhovsk bog	Bottom sediments:		
	peaty	0.37	55.8
	silt	0.75	95.6
Distance from the bog's bank, m:	Soil:		
7	bog soil	0.63	88.4
25	the same	0.07	3.4
500	brown forest soil	0.03	Not detected

As based on the field data and mathematical models the dose burden on the critical groups of the population during the period of the BNPP operation was calculated (Koltik, 2001). The critical group exposed to radiation due to the gas – aerosol fallouts, is the population of the town located near the BNPP (Zarechny). Up to 1979 this group was also a critical one that was influenced on the way of radiation from the liquid effluents discharged from the BNPP, and since 1980 this group includes the settlements on the trail of the discharge (the Olkhovsk bog – the Olkhovka River – the Pyshma River). For the time of operation of all the three BNPP Units the dose burden on the critical groups of population did not exceed the annual permissible limits. Thus, the average total individual dose is 85 mcSv/year, with gas-aerosol fallouts – 64 mcSv/year (the permissible dose is 200 mcSv/year) and liquid discharged effluents – 21mcSv/year (the permissible dose is 50 mcSv/year) (Fig. 8).

Maximum individual risks for the population induced by the reactors AMB-100 (Unit 1) and AMB-200 (Unit 2) are $3.0 \cdot 10^{-5}$/year, and by the fast reactor BN-600 (Unit 3) is $3.5 \cdot 10^{-7}$/year, that does not exceed the limit of individual risk for population ($5 \cdot 10^{-5}$/year). Risk for the total population from the BN-600 is approximately 3 orders of magnitude lower than that from the channel-type reactors, proving that the Units with fast neutron reactors are relatively safe.

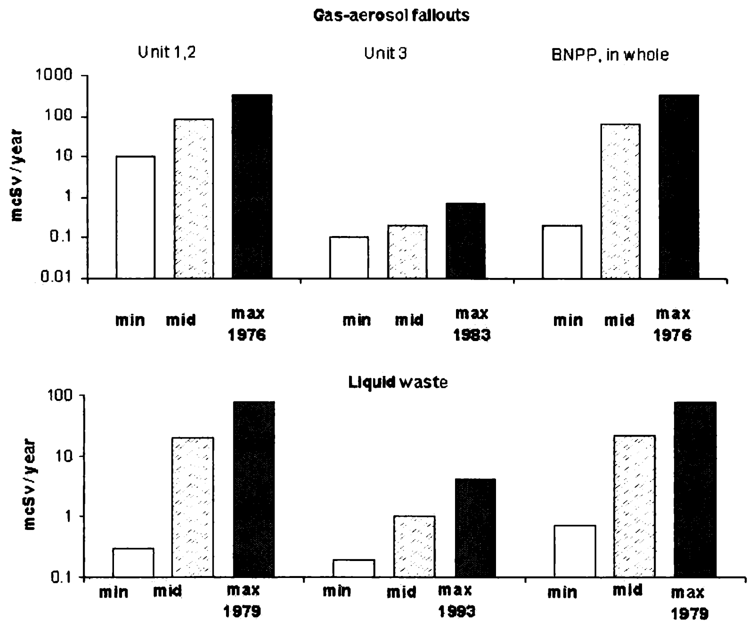

Figure 8. Individual dose burdens on the critical groups of population due to the gas-aerosol fallouts and liquid effluents discharged from the BNPP (Koltik, 2001).

2.5. Peculiarities of radionuclides accumulation by plants

A significant role in the redistribution of radionuclides in aquatic and terrestrial ecosystems belongs to the plants. The accumulation of radionuclides by plants depends on the peculiarities of their type, physicochemical properties of soils and several ecological factors. It is shown as the example, that some species of plants can be indicators of radioactive contaminations in the environment

(Mattson, Liden, 1975; Moiseev, Ramzaev, 1975; Kulikov, Tikhomirov, 1978). For the estimation of the radionuclide receipt by the plants, different indicators are used. One of them is the accumulation coefficient (AC). It characterizes the ratio of radionuclide concentrations in a dry substance of plants and in a soil. A usage of this value reflects a phenomenological picture of radionuclide accumulation by living organisms in controlled conditions of a test. In the conditions of a wide range of density of an area contamination the most informative indicator of the concentrative ability of plants is a transition coefficient (TC) value, which is calculated as the ratio of radionuclide in the overground mass of plants (Bq/kg) to the soil contamination density (kBq/m^2) (Korneev, Sirotkin, 1986).

In the course of the radioecological examination of the Olkhovsk bog the overground mass of five species of bog plants (which were the most frequently met) were analyzed: *Typha latifolia L., Carex vesicaria L., Phragmites australis (Cav.), Bidens tripartite L.* and *Lemna minor L.* (Table 20). A maximum radionuclide specific activity is noted for the freshwater floating plant *Lemna minor*. The ^{60}Co content in it is 4.6, and those of ^{90}Sr and ^{137}Cs are 1.1 and 25.8 kBq/кg of dry mass, respectively. Contrary to *Lemna minor*, the representatives of the fixed plants accumulate the above radionuclides in their overground mass 2 to 60 times less.

In order to understand a role of plants in the migration streams of radionuclides one needs to compare their accumulative ability on the contaminated areas and control plots located outside the effect of the radioactive contamination source under study. Such areas, which are contaminated with only global fallouts, were examined in the Central Yakoutya region and the Southern Urals (Trapeznikov et. al., 2007). The investigations made showed that the concentration of both ^{90}Sr and ^{137}Cs in the plants growing in such areas were within 2Bq/kg to 100Bq/kg, and TC was from $1.5 m^2 kg^{-1} \times 10^{-3}$ to $38.0 m^2 kg^{-1} \times 10^{-3}$.

Table 20. Accumulation of radionuclides by plants in the Olkhovsk bog, kBq/kg dry mass

Species	^{60}Co	^{90}Sr	^{137}Cs
Tipha latifolia L.	0.15±0.04	0.54±0.05	6.80±2.50
Carex vesicaria L.	0.08±0.01	0.28±0.02	5.40±1.10
Phragmites australis (Cav.)	0.12±0.02	0.69±0.02	5.70±0.08
Bidens tripartite L.	0.77±0.17	0.56±0.09	10.90±2.70
Lemna minor L.	4.60±0.34	1.10±0.13	25.80±2.80

By using a transition coefficient the accumulation ability of the plants growing on the contaminated area of the bog's bank zone of the Olkhovsk bog was compared with that of the control plots (Table 21). It is seen from the table that the concentration of ^{137}Cs in the overground mass of the plant types studied is one to two orders of magnitude higher than that on the background area. For ^{90}Sr these variations are less expressed. For $^{239-240}Pu$ they are practically remaining on the same level. The attention is drawn to the low values of specific activity of this nuclide in plants. In the contamination area and on the control plots the specific activity is not more than hundredth fractions of Bq in kg of a dry mass. At the same time the TC for radionuclides in plants taken from the contaminated soils and soils of the control plots in some cases are essentially different. A lack of a direct dependence between the content of radionuclides in the soils and their concentration in overground mass of plants can be explained by an influence of several factors: physicochemical properties of soil, a form in which the emitters are present in it, ecological and climatic conditions of growing, which are rather difficult to control in a natural situation. However, it should be noted that in the region of the Olkhovsk bog *Urtica dio*ica (TC=96.6) has the highest ability to accumulate ^{90}Sr, and *Bidens tripartita* (TC=48.4) has the highest ability to accumulate ^{137}Cs. In the background area maximum values of TC were found for ^{90}Sr and ^{137}Cs in *Filipendula ulmaria.*

Table 21. Accumulation of radionuclides by plants in the zone of liquid waste effluents discharged from the BNPP (1 - Bq/kg dry mass, 2 - TC, $m^2kg^1 \times 10^{-3}$)

Species	^{90}Sr		^{137}Cs		$^{239-240}Pu$	
	1	2	1	2	1	2
Chamaenerion angustifolium L.	24 9	4.0±0.7 4.5±0.3	175 16	1.4±0.4 4.0± 0.5	- 0.04	- 0.4
Urtica dioica L.	580 15	96.6±25.0 7.5±1.8	2043 12	15.9±0.5 3.0±0.3	0.05 0.03	0.4 0.3
Filipendula ulmaria L.	62 65	10.3±1.0 32.5±2.4	247 93	1.9±0.3 23.2±1.6	0.03 0.02	0.5 0.2
Bidens tripartite L.	53 20	8.8±0.7 10.0±1.3	6200 50	48.4±2.0 12.5±1.3	-	-

Note. Data above the line is for the zone of liquid waste discharged from the BNPP; data under the line is for the background zone.

A study of peculiarities of radionuclide accumulation by woody plants that are growing in the periodically flooded bank zone of the Olkhovsk bog shows that the ^{90}Sr specific activity is 2 to 5 times and ^{137}Cs specific activity is two orders of magnitude higher than the contamination level of the plants growing in watershed areas that are not influenced by the liquid discharges from the BNPP (Fig.9).

It should be noted that in most of the cases the true differences in the accumulative ability of *Betula pendula Roth.* and *Salix cinerea L.* have not been found. The ability of the on-land bodies of the woody plants to accumulate ^{137}Cs decreases in the following way: leaves > small branches > trunk; this dependence is less expressed for ^{90}Sr (Yushkov, 2000; Yushkov et al., 2002).

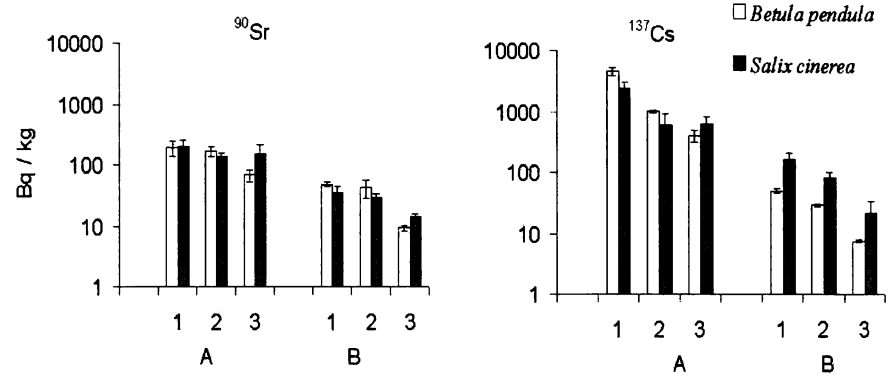

Figure 9. Radionuclide distribution in on-land bodies of the woody plants growing on the bog's bank (A) and in watershed areas (B): 1- leaves, 2- small branches, 3- trunk.

3. Physicochemical forms of radionuclides in soils

In the previous chapters the peculiarities of the behavior of radionuclides received by the soil-plant cover from different sources have been described. The manner of radionuclide interactions with soil, first of all, is determined by physicochemical properties of substances and materials, in a content of which radionuclides entered the environment. In order to reveal mechanisms and regularities of radionuclide migration one needs to have a notion of their physicochemical forms in soils.

It is known that the significant part of global radioactive fallouts is well soluble. In the nonsoluble fraction of the fallouts the content of ^{90}Sr is of 8 to18%, and that of ^{137}Cs is of 28 to 67%. In this fraction the condition of ^{90}Sr is mainly exchangeable and that of ^{137}Cs is an acid-soluble one (Pavlotskaya, 1974; 1981). A further transformation of radionuclides' physicochemical status is determined by their own properties and soil – ecological conditions. In spite of the variety of the radionuclide content and sources of receipt, approaches to the estimation of the physicochemical condition of the pollutants are quite well unified; as a rule, the groups of compounds differentiated by a degree of strength of their bond with soil are studied. By the method of sequential soil extractions: water-soluble, exchangeable, acid-soluble and fixed groups of compounds are differentiated (Molchanova et. al., 2006). The most mobile are the groups of water-soluble and exchangeable compounds, the less mobile are the acid-soluble ones, and the fixed compounds are those that stay in the soil after their treatment with acids solutions. The qualitative content of the differentiated groups of compounds is given in Table 22.

Table 22. Qualitative content of physicochemical forms of radionuclides in soils

Physicochemical form	Desorbent	Group of compounds
Water-soluble	Distilled water	Water-soluble salts of inorganic acids and organic compounds (complexes, salts)
Exchangeable	Solutions of salts of various normality	Elements bonded with soils on mechanism of ion- exchange.
Acid-soluble	Solutions of acids of various normality	Carbon salts, loosely absorbed by oxides, hydroxides of iron and aluminum, clayey minerals; fulwates, hardly exchangeable ions.
Fixed		Ions bonded tightly (nonexchangeable) by an organic substance of the soil, when being in the content of semi-oxides of iron and aluminum, and adsorbed by the type of isomorphic substitution in crystal lattices of minerals.

The radionuclides are distributed in these groups of compounds, first of all, depending on the prevailing mechanism of their interaction with the soil: an ion-exchange absorption, a chemical co-precipitation (a formation of hardly soluble chemical compounds), an isomorphic substitution in crystal lattices of minerals.

There is a dynamic equilibrium among all the radionuclide physicochemical forms, the result of which is that strongly fixed ions in the soils can transfer into a mobile condition and vice versa (Vozbutskaya, 1968; Pavlotskaya, 1974; Marey et.al., 1974). The intensity of such transfer depends on the type of soils and their genetic structure, a type of vegetation, a season of a year, intensity of the microbiological processes, agrometeorological conditions and ecological factors. A form of a radionuclide bond with a soil can change with time, and, as a rule, the result is an increase in the relative content of tightly fixed forms of radionuclides ("aging" effect).

Proceeding from the said above, the physicochemical forms of the radionuclides in the soils adjacent to the Olkhovsk bog were estimated. For the estimation the key patches were embedded at the distance of 10m and 500m from the bank of the Olkhovsk bog. In the first case the soil cover contamination with ^{90}Sr and ^{137}Cs is mainly due to liquid radioactive effluents discharged from the BNPP, and in the second case they are due to the global fallouts from the atmosphere. The results show a little difference in the physicochemical status of the radionuclides in the soils located at different distances from the bog (Table 23); ^{90}Sr is present in the soils preferentially in the exchangeable and acid-soluble forms, and ^{137}Cs is – in the content of tightly fixed compounds.

Table 23. Forms of radionuclides in the soils of the Olkhovsk bog's bank, %

Distance from the bank, m	Water-soluble	Exchangeable	Acid-soluble	Fixed
		^{90}Sr		
10	12.1±3.8	56.3±8.5	31.6±3.5	b.d.l.*
500	7.4±1.9	60.2±6.7	32.4±5.9	b.d.l.
		^{137}Cs		
10	3.4±0.6	5.4±1.1	15.3±3.1	75.9±4.5
500	7.4±2.5	9.7±2.5	18.0±2.4	64.9±6.9

* – below the detection limit

It should be noted that the manner of the distribution of the physicochemical forms of ^{90}Sr does not change within a depth of 25cm-layer of soil. At the same time the results of the dispersion analysis show that a fraction of fixed ^{137}Cs decreases actually and regularly from 67 to 52% (F=7.8 and 28.5 at $F_{0.05}$=3.3) with an increasing depth. Consequently, the content of the exchangeable ^{137}Cs increases from 6 to 19% with depth. Thus, the vertical migration of ^{137}Cs in soils is accompanied by a differentiation of its forms with depth that leads to an enrichment of the lower layers with mobile cesium. For a comparison there were determined the content of physicochemical forms of ^{90}Sr and ^{137}Cs in the bog's peaty deposits, contiguous with the soils by the vector of runoff. In both the soil and the peaty deposits, ^{90}Sr is mainly in the exchangeable (60%) form and the acid-soluble one (35%). The content of water-soluble ^{90}Sr (2%) in the peat is lower than in the soil. It is found that the content of water-soluble cesium is also lower in the peat than in the soils. It makes tenth fractions of percent and does not change with depth and that is also proved by the results obtained from the dispersion analysis (F=27 at $F_{0.05}$=3.3). The latter is true for the exchangeable and fixed forms, which are equal to 8.9 and 57%, respectively. The total content of mobile ^{137}Cs at all the depths of peaty deposits is not more than 10%.

Conclusion

The increasing effect of man on the environment makes acute the contradictions between a developing industry and biological, i.e. productive forces of the Earth. One of them is a receipt of significant quantities of natural and artificial radionuclides by the biosphere of the Earth. These radionuclides are released in the course of the development of nuclear industry, power engineering, nuclear weapons tests, and emergency situations at nuclear power sites. As a result, they are continuously accumulated by living and dead components of biosphere that leads to an increasing background of ionizing irradiation.

The global radioactive contamination of Earth's biosphere happened in the mid-XXth century as a result of intensive tests of nuclear weapons. The essential source of man-made radionuclides is also the nuclear accidents and incidents at the enterprises of the nuclear power generation complex. However, even at their normal operation there are a release of a certain set of radionuclides together with gas-aerosol fallouts and discharged liquid effluents into the environment. This fact determines the necessity and importance of conducting radioecological researches of natural ecosystems in the zones adjacent to nuclear power stations.

One of the largest nuclear sites of the Ural region of Russia is the Beloyarsk Nuclear Power Plant that works in a normal operation mode. The first stage of the BNPP comprised two Units that were commissioned in 1964 and 1967. In 1969 they reached a rated power of 300 MW, and they were put out of operation in 1989. The second stage of the BNPP includes the Unit with the fast neutron reactor BN-600, that has been operating since 1980. Besides, one more Unit with the fast neutron reactor BN-800 is under construction there.

The 30-km zone of the BNPP is being examined during many years (from 1978 to the present time), and it has been found that ^{90}Sr and ^{137}Cs gas-aerosol fallouts from the BNPP do not make any noticeable contribution to the contamination of the adjacent terrestrial ecosystems. The exclusion is the soil-plant cover, which is in the region of the fallouts torch landing, where a higher content of ^{137}Cs and plutonium isotopes has been noted. As a result of the long-term discharge of low active waste waters from the BNPP into the Olkhovsk bog the impacted zone has formed, that is contaminated with ^{90}Sr, ^{137}Cs and $^{238\text{-}240}Pu$. The stock of long-living, dose-forming radionuclides (mainly ^{137}Cs) in the bottom sediments of the bog is about $3.7 \cdot 10^{12}$ Bq. The substantial amounts of them contaminate a line of the near – bog soils at the distance of 10 to 15m from the bank. Besides, the Olkhovka River waters carry away $1169 \cdot 10^{6}$ Bq of ^{90}Sr, $1581 \cdot 10^{6}$ Bq of ^{137}Cs and $2.1 \cdot 10^{6}$ Bq of $^{238\text{-}240}Pu$ from the bog to the open hydrographic network annually. A contribution of liquid waste discharged from the BNPP into the contamination of the components of the natural ecosystems with plutonium fluctuates from 53.1 to 95.6%.

In order to reveal the mechanisms and regularities of the radionuclides migration the estimate of the levels of their content in the soil-plant cover at the contaminated areas was accompanied with the determination of the physicochemical forms in the pollutants, that were characterized by their different bond with the soil. In the zone of liquid waste water discharged from the BNPP ^{90}Sr is in the soils and it is mainly in the exchangeable and acid-soluble forms. The substantial part of ^{137}Cs was found in the composition of tightly fixed compounds. The vertical migration of this radionuclide in the soils is accompanied with the differentiation of its forms with depth that leads to an enrichment of the layers below with mobile compounds.

Woody and herbal plants are a filter on the way of the radioactive fallouts from the atmosphere. Besides, most of the types of forest and meadow herbs are the main chain leading to a human being. Therefore the main objects of our researches were the dominating types of the forest and meadow plants. In the condition of a wide range of densities of the radionuclide contamination of the soil, the most informative indicator of the accumulative ability of plants is the transition coefficient (TC). The comparison of TC values calculated for contaminated and control plots makes possible to estimate the contribution of the Nuclear Fuel Cycle enterprises into the contamination of the plant cover of terrestrial ecosystems. The system analysis of such material shows that the specific activity of both ^{90}Sr and ^{137}Cs in global fallouts for the plants growing in different climatic zones is within 2 Bq/kg to 100 Bq/kg, and

TC is 1.5 to 32.0$m^2 kg^{-1} x10^{-3}$. Within the limits of the bank zone of the Olkhovsk bog the specific concentration of ^{137}Cs in the woody and herbal plants is higher than in control plots.

The calculation of dose burdens on the critical groups of population shows that they have not exceeded the permissible annual limits during the operation life of all the three Units of the BNPP. This conclusion can be an argument in favor of the development of nuclear power provided a safety operation of its nuclear sites.

More than half a century history of radioecological researches shows that the ionizing radiation of a man –made origin is a global ecological factor. Its scale and intensity to a greater extent is determined by the vectors of a nuclear industry development, specific technological cycles of the nuclear fuel cycle enterprises and stability of their operation. In some regions of Russia the ecological situations has become complicated and needs systematic radioecological researches. The importance of the latter is emphasized also by the fact that the main sources and ways of entering radioactive and other man – made contaminations into the biosphere have the same base and the contaminations themselves have likely mechanisms of migration and distribution in the components of the biosphere. Therefore the method used by radioecology based on the quantitative estimate of the impacting factors can be successfully used for studying ecological consequences of any man-made contaminations.

Acknowledgments

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The BNPP is one of the large nuclear sites of the Ural region. During several years of investigations there were estimated the contributions made by the gas-aerosol fallouts and liquid radioactive waste effluents discharged from the BNPP at normal operation mode into the contamination of natural ecosystems. In general a 50-year period of the BNPP operation did not lead to any increase in the content of 90Sr,137Cs and 238-240Pu in the soil-plant cover of its 30-km zone. A long –term discharge of waste waters from the BNPP into the Olkhovsk bog – river ecosystem resulted in the increase of the content of the radionuclides in water and in the bottom sediments of the bog. The stock of radionuclides in the Olkhovsk bog is about 3.7•T Bq at present time; and 99% the radionuclides are in the bottom sediments. This fact makes the Olkhovsk bog to be a potential source of contamination of the conjugated territories and the open hydrographic network. An annual departure of the radionuclides from the Olkhovsk bog was calculated. It is 2. 1M6Bq/yr for isotopes Pu, 1170 MBq/yr for 90Sr and 1581 MBq/yr for 137Cs.

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