The problems of over-wetting and swamping of radioactive contaminated territories within the Pripyat River basin

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Abstract
The territory of the Pripyat River basin within 30-km exclusion zone around the Chernobyl nuclear power plant is still remains an open source of radioactive contamination. The basic problems of radiation safety of the exclusion zone are connected with radionuclide washout with surface run-off into the river systems, radioactivity carry-over beyond the bounds of the exclusion zone and sharing in formation of water quality of the Dnieper River – the main waterway of Ukraine. The most contaminated region of the exclusion zone is the Krasnensky flood plain on the left bank of Pripyat River. During 1991-1995 the complex of hydraulic engineering structures as flood protection dams was constructed here, which preventing washing away of radioactive substances from soils. In its turn it was by the reason of strengthening of over-wetting and swamping processes within embankment territories. As a result – on a background of the common tendencies of increase of the mobile forms of ^{90}Sr in soils of catchment territories and bottom sediments of the exclusion zone, there is an acceleration of mobilization processes of deposited forms of ^{90}Sr, and also their migration and redistribution in closed aquatic landscapes.

Keywords
Chernobyl exclusion zone; dammed territories; flood lands; Pripyat River; remobilization of radionuclides, ^{90}Sr

INTRODUCTION

Despite the years passed since the Chernobyl accident in 1986, the territory of the Pripyat River basin within the 30-km exclusion zone around the Chernobyl nuclear power plant (NPP) is still the open source of radionuclide contamination with a complex distribution structure in different landscapes and characterized by dynamic character of the state of radioactive substance forms, which affect their migration and redistribution by components of ecosystems. The basic questions of radioactive safety of the restriction zone concern radionuclides wash-off with surface drainage water to river network, their export outside the restriction zone and affection of the water quality in Dnieper River – the main waterway of Ukraine. In this connection the radiation condition of surface water of the Chernobyl exclusion zone has huge importance.

Self purification of closed water bodies in the Chernobyl exclusion zone is extremely slow process. Therefore, ecosystems of the majority of lakes, dead channels and crawls possess high level of radionuclide contamination of all the components. The main quantity of radionuclides in aquatic landscapes of the exclusion zone are deposited to bottom sediment of closed water bodies, hence, the distribution of radioactive substances in biotic and abiotic components of hydrobiocoenoses is defined by biogeochemical regularities and transformations of radioactive substances in bottom sediments of water bodies and in soils of adjacent territories.

The main purposes of the submitted researches were the analysis of results of surface waters radionuclide monitoring within territory of the Chernobyl exclusion zone and the evaluation of

impact of water-protection structures within the left-bank of Pripyat River flood-lands on the swamping processes influencing on radionuclide mobilisation.

RESULTS AND DISCUSSION

The greatest contribution in radionuclide contamination of Pripyat River and the formation of transference of radionuclides into Dnieper River reservoirs system brings in radionuclide migration from periodically flooded sites of Pripyat River flood-lands. The most contaminated area of the exclusion zone is Krasnensky flood plain, representing water-marsh lands on the left bank of Pripyat River and formed in result of the river meandering. During 1991–1995 a complex of hydraulic engineering structures as flood protection dams was constructed (Fig. 1), which preventing washing away of radioactive substances from soils.

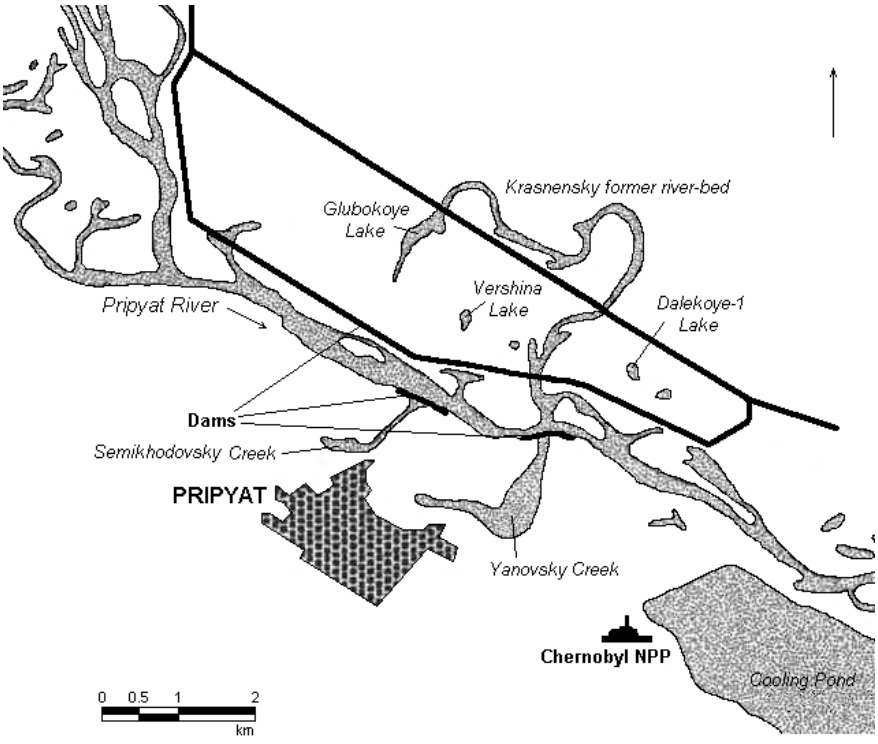

Fig. 1. The map of dams and reservoirs of Krasnensky flood-lands within the inner (10 km) exclusion zone of the Chernobyl NPP

Krasnensky flood plain is characterised by variety of reservoirs, which are taking place at different stages of successional changes (Gudkov et al., 2003). Among it meanders there are more 60 natural lakes and artificial (land-reclamation) reservoirs by the general area about 12 sq. km. The basis of their vegetative cover is communities of higher aquatic plants – the main objects of described researches.

For all water objects, studied since the early 1990-s, located in the Chernobyl accident exclusion zone, the general tendency in variations of radionuclide concentration in water of these objects is a decrease of ^{90}Sr and ^{137}Cs specific activity, which dynamics is firstly related to intensity of water exchange processes, with the only exclusion for closed water bodies of the left-bank flood-lands of Pripyat River, located at the territory of dammed area of Krasnensky flood plain (Glubokoe Lake and Dalekoe-1 Lake), where recently, at the background of ^{137}Cs specific activity stabilization, a tendency to ^{90}Sr concentration increase was observed (Table 1).

More demonstrably a tendency of ^{90}Sr specific activity increase in components of lake ecosystems within Krasnensky flood plane in comparison with other water bodies of the exclusion zone was registered for higher aquatic plans. Within the period of investigation since 1989 till 2004, dynamics of the main radionuclide concentrations in tissues of the higher aquatic plants from river ecosystems of the exclusion zone indicated a decrease of specific activity of ^{90}Sr and ^{137}Cs (Figure 2a, b). So far as concerns closed of low flowage water bodies, the most representative retrievals

Table 1. Dynamics of the mean annual content of radionuclides in water of some water bodies in the Chernobyl exclusion zone, Bq/l

Year	Yanovsky Crowl		Dalekoe-1 Lake		Cooling pond		Azbuchin Lake		Glubokoe Lake		Pripyat River (Chernobyl town)		Uzh River (Cherevach vill.)	
	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs
1997	30	5.2	45	4.5	2.2	2.8	85	12.7	100	13.2	0.25	0.16	0.26	0.08
1998	35	4.3	50	3.4	1.8	3.1	120	17.2	120	14.0	0.30	0.14	0.32	0.14
1999	38	3.7	45	2.8	1.9	3.1	190	22.8	120	13.6	0.50	0.15	0.25	0.10
2000	49	2.8	48	1.7	1.7	2.7	133	13.0	103	7.8	0.22	0.11	0.16	0.10
2001	26	2.7	35	2.6	1.5	2.1	110	9.9	79	7.1	0.23	0.12	0.18	0.09
2002	23	3.2	29	2.0	1.4	2.1	52	5.6	74	7.2	0.17	0.05	0.08	0.05
2003	22	2.4	40	2.3	1.7	2.1	49	8.7	102	6.8	0.15	0.03	0.11	0.04
2004	19	2.8	55	2.2	1.6	1.8	56	6.7	135	6.2	0.18	0.03	0.17	0.04

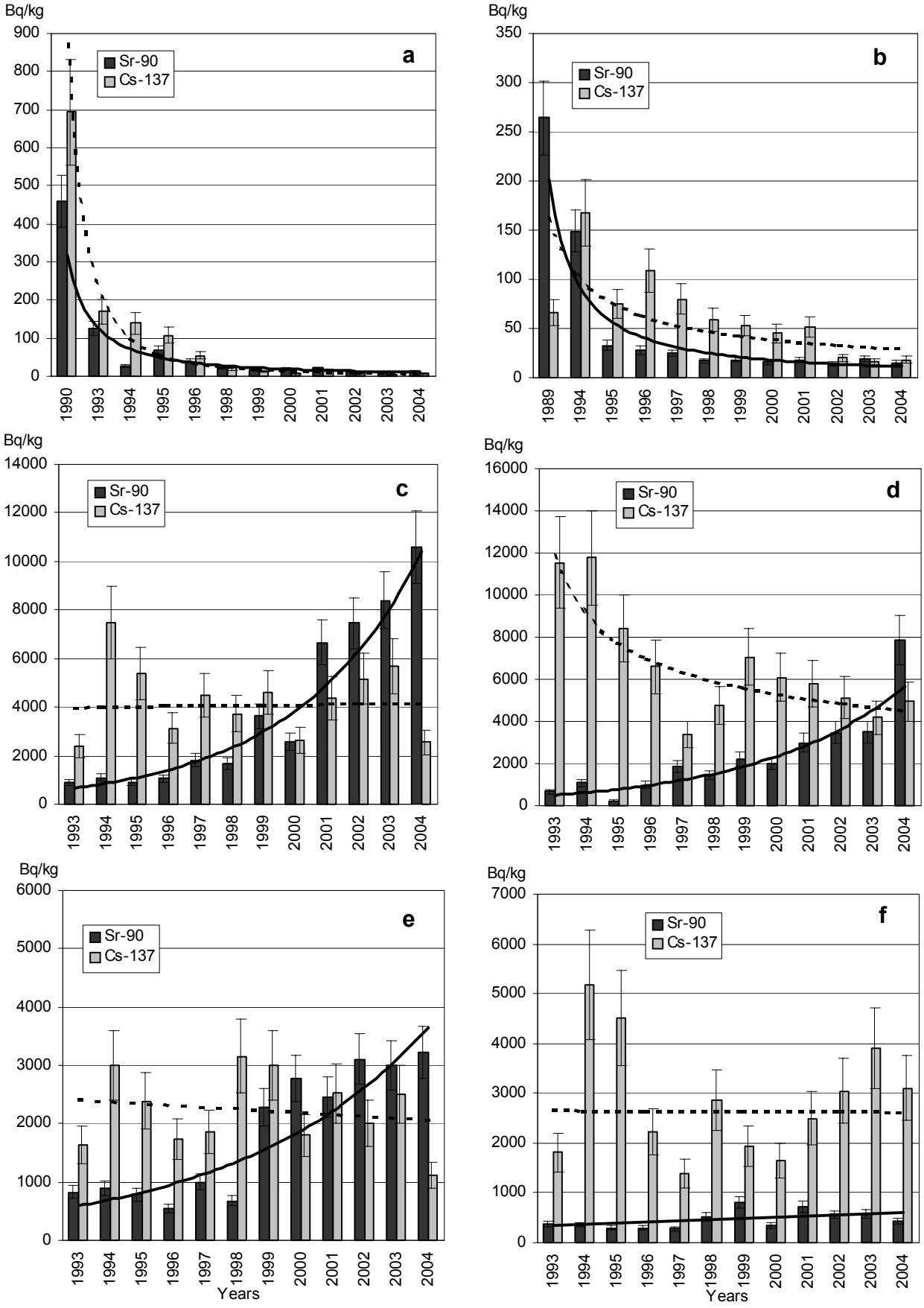

Fig. 2. Dynamics of radionuclide content in higher aquatic plants of the Chernobyl exclusion zone: a – lesser reedmace (Pripyat River); b – fennel pondweed (Pripyat River); c – water-soldier (Glubokoe Lake); d – yellow water lily (Glubokoe Lake); e – yellow water lily (Dalekoe-1 Lake); f – common reed (Chernobyl NPP cooling pond). Continuous line denotes ^{90}Sr specific activity trend; dashed line denotes ^{137}Cs specific activity trend

obtained in the period of 1993-2004 have shown that since the late 1990-s the higher aquatic plants related to different ecological groups are indicating a frank tendency to ^{90}Sr content increase in tissues (Figure 2c–e). Primarily, this tendency was observed for test materials, sampled in the period of 1993-1998 in Glubokoe lake (Kaglyan, 2003), and then was confirmed by tests performed in 1998-2004 for Dalekoe-1 Lake. So far as concerns ^{137}Cs, its specific activity in higher aquatic plants of the lakes under study either decreases or remains practically constant. Hence, in the middle 1990-s specific activity of ^{137}Cs in tissues of higher aquatic plants from Krasnensky flood plain was much higher than specific activity of ^{90}Sr in them, whereas in the late 1990-s these values became comparable, and at present specific activity of ^{90}Sr is much higher than that of ^{137}Cs, the concentration of which either decreasing or remaining practically constant.

In the cooling pond of Chernobyl NPP, due to more intensive water exchange and, at the same time, high contamination density of bottom sediments with ^{137}Cs, which defines the ratio between ^{90}Sr and ^{137}Cs contents in water, anomalous for water bodies of the restriction zone, dynamics of ^{90}Sr specific activity in tissues of macrophytes is not so clear, and ^{137}Cs specific activity varies within a broad range showing no clear linear dependence (Figure 2f).

It is suggested that ^{90}Sr specific activity in tissues of macrophytes from Krasnensky flood plain increases due to dynamics of radionuclide transformation in soils of water catchment areas and bottom sediments of water bodies. Due to construction after the Chernobyl accident a complex of flood control dams, which preventing radioactive substance washing off the soils of contaminated areas not only, but changed the hydrological regime of flood plain flows during floods, this became the reason for intensification of waterlogging and swamping of dam-locked areas. This confirms the increase of a role of water-marsh floristic complex in structure of vegetative cover of Krasnensky flood-lands (Gudkov et al., 2002). As a result of swamping, at the background of general tendencies of ^{90}Sr mobile form increase in the soils of water catchment areas and bottom sediments of the exclusion zone water bodies; in swamped soils of Krasnensky flood plain fulvic and humic acid concentration increases, that decreases pH-value in water and intensifies a denuding of water-soluble forms of ^{90}Sr forming soluble complexes with fulvic acids. Hence, an increase of concentrations of mobile forms of the radionuclide and their inclusion to biotic turnover of aquatic ecosystems are observed. This also confirms the increase of ^{90}Sr specific activity, observed in recent years in Krasnensky flood plain lakes at the background of stabilization of this index for ^{137}Cs.

The tendency of the root contamination of plant tissues by ^{90}Sr was also observed for terrestrial plants in the exclusion zone (Ivanov, 2001; Kashparov, 1998, 2001). Currently, some authors (Sobotovich et al., 2002) suggest that ^{90}Sr mobility in soils of the exclusion zone is maximal, and this will last during the nearest decade. Thereafter, the rate of radionuclide decomposition will exceed the rate of its mobilization.

CONCLUSION

The construction of a complex of flood retarding dams and degradation of existing melioration systems at the site of the left-bank flood plain of Pripyat River implied a change of hydrological regime and the character of water object overgrowth. The absence of flowage in water bodies, stagnation effects during spring flooding and seasonal runoffs intensified waterlogging and swamping of dam-fenced territories. As a result, at the background of general tendencies of ^{90}Sr mobile forms increase in the soils of water catchment areas and bottom sediments of the exclusion zone water bodies located at dam-fenced sites, as well as increasing intensity of this radionuclide concentrating by higher aquatic plants and, obviously, other autotrophic organisms. For some species of macrophytes, ^{90}Sr concentration compared with the early 1990s have increased by more than an order of magnitude and exceed the specific activity of ^{137}Cs. Obviously the specific activity

of ^{90}Sr will also increase at higher trophic levels, however, at present, such dynamics was not reliably detected. It is suggested that for radioecological monitoring of aquatic ecosystems in the restriction zone, higher aquatic plants possessing high concentration factor values of radionuclides are the most sensitive test-objects for recording increasing specific activity of mobile forms of radionuclides in the water of test site water bodies.

The results of tests performed confirm the tendency to further deterioration of the radiation situation in aquatic ecosystems of the exclusion zone. Swamping of contaminated territory leads to acceleration of ^{90}Sr deposited form mobilisation processes and their migration and redistribution in closed aquatic landscapes. Hence, an original "depot" of mobile forms of radioactive substances is formed, which in high-flood periods may become a source of increasing ^{90}Sr drainage to Pripyat River and then outside the exclusion zone. In this connection, the necessity to implement hydraulic engineering procedures preventing underflooding of territories with high densities of radionuclide contamination; optimisation and enhancement of radioecological monitoring system, and further development of investigations of radionuclide behaviour in aquatic ecosystems of the exclusion zone – the important components in the complex of measures related to forecasting and minimisation of the Chernobyl disaster consequences.

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REFERENCE

Gudkov D.I, Zub L.N., Savitsky A.L., Nazarov A.B., Kaglyan A.E. (2002). Macrophytes of the exclusion zone of the Chernobyl nuclear power station: the formation of plant communities and peculiarities of radioactive contamination of the left-bank floodplain of the Pripyat river. *Hydrobilogical Journal*, **38**, 5, 116–132.

Gudkov D.I., Zub L.N., Savitsky A.L. (2003). Hydrotechnical facilities within the Chernobyl nuclear power plant exclusion zone: impacts on hydrologic regime and plant growth patterns of floodplain water bodies of the Pripyat River. *Water Science and Technology*, **48**, 7, 89–96.

Ivanov Yu.A. (2001). Dynamics of radionuclide redistribution in soils and vegetation. In: *Chernobyl – the Exclusion Zone.* Ed. V.G. Barjakhtar, Kiev, Naukova Dumka. (in Ukrainian)

Kaglyan A.E. (2003). *The Features of ^{90}Sr and ^{137}Cs Accumulation by Hydrobionts and Abiotic Components of Water Bodies in the Restriction Zone of Chernobyl NPP.* Candidate Dissertation Thesis on Biology, Kiev (in Ukrainian).

Kashparov V.A. (1998). Contamination by ^{90}Sr of the exclusion zone's territory. *Bulletin of Ecological State of the Restriction Zone and the Zone of Compulsory (Mandatory) Evacuation*, 12, 67–74 (in Ukrainian).

Kashparov V.A. (2001). *Formation and Dynamics of Environmental Radioactive Contamination During the Accident at the Chernobyl NPP and After the Accident.* Ed. V.G. Barjakhtar, Kiev, Naukova Dumka (in Ukrainian).

Sobotovich E.V., Bondarenko G.N., Kononenko L.V. *et al*. (2002). *Geochemistry of Production Induced Radionuclides*, Kiev, Naukova Dumka (in Russian).