BOTTOM SEDIMENTS OF THE RESERVOIRS IN THE LOWER REACHES OF THE SOUTHERN BUG RIVER AS A DEPOT OF ANTHROPOGENIC RADIONUCLIDES

Kostiantyn Grygoriev, Liudmyla Grygorieva*, Olena Makarova

Petro Mohyla Black Sea National University, Mykolaiv, Ukraine;

**Corresponding author: ludmila.grygorieva@chmnu.edu.ua*

Abstract.*The article presents the materials of radioecological studies of the authors on the accumulation capacity of bottom sediments in relation to radioactive substances entering the Southern Bug River during discharges from the South Ukrainian NPP. The aim of the study was to investigate the properties of bottom sediments in the channel reservoirs of the lower reaches of the Southern Bug River (Tashlyk and Oleksandrivske reservoirs) in terms of radionuclides retention.*

The article analyses the content of radionuclides in water and bottom sediments of the Tashlyk and Oleksandrivske reservoirs. The coefficients of accumulation of radionuclides in the bottom sediments of these reservoirs were calculated. Differences between the Tashlyk and Oleksandrivske reservoirs were found in a number of hydrochemical parameters: temperature, hydrogen, alkalinity, dry residue, and dissolved oxygen. It is shown that these differences between the hydrochemical differences of the Tashlyk and Oleksandrivske reservoirs determine significantly lower coefficients of radionuclide accumulation in the bottom sediments of the Tashlyk reservoir. The presence of an inverse linear relationship between water salinity and the values of ^{137}Cs *and* ^{134}Cs *accumulation coefficients in the sediments of the Tashlyk and Oleksandrivske reservoirs was established, and a regression equation was determined that allows estimating the accumulation coefficient of cesium radioisotopes in sediments depending on water salinity.*

DOI: 10.24263/EDSD-2023-5-15

Introduction. Monitoring of bottom sediments plays a crucial role in assessing the ecological state of water bodies in general and adjacent areas, as the average composition of bottom sediments can reflect the composition of the humus soil horizon of the water body basin. Therefore, most studies on radioecological monitoring of water bodies are devoted to bottom sediments [2-4]. Water bodies are constantly undergoing metabolic processes that make up a single exchange system, which includes water and bottom sediments. Bottom sediments, which are a direct source of accumulation, play an important role in the formation of a qualitative assessment of water and coastal areas, as well as the content of toxic substances in it. Changes in the physical, chemical and other conditions of the aquatic environment can lead to an imbalance in the sediment-water system, which can cause secondary pollution of the water body, even in the absence of sources of pollutants from the outside [1]. This demonstrates the relevance of conducting monitoring studies of both industrially loaded and conditionally clean water bodies. In this context, a special role should be given to the study of bottom sediments of surface water bodies in the lower reaches of the Pivdennyi Buh River and their ability to accumulate and retain radioactive substances entering the Pivdennyi Buh River during discharges from the South Ukrainian NPP. The aim of the study was to investigate the properties of bottom sediments of the channel reservoirs in the lower Pivdennyi Buh River (Tashlyk and Oleksandrivske reservoirs) in terms of radionuclide retention.

Materials. The study materials were the official materials of the Energoatom Company on radionuclide discharges from SUNPP (1982-2020) [5], the results of radioecological researches by the authors. The Tashlyk and Oleksandrivske reservoirs belong to the South Ukrainian Energy Complex. The Tashlyk Reservoir is intended to serve as a cooler for water coming from the NPP. After the Tashlyk Reservoir, the water enters the Oleksandrivske Reservoir, which in turn is connected to the Southern Bug River.

Results and Discussion. The content of radionuclides in the water of the reservoirs in the period from 1991 to 2017 is shown in Tables 1, 2.

Table 1.

Radionuclide concentrations in water, Bq/l

Reservoir	Radionuclide	2013 year	2014 year	2017 year	2021 year
Tashlyk Reservoir	^{3}H	1,66E+02	1,61E+02	1,66E+02	1,66E+02
	^{90}Sr	4,30E-02	3,54E-02	4,30E-02	4,30E-02
	^{134}Cs	9,05E-03	9,05E-03	9,05E-03	9,05E-03
	^{137}Cs	1,14E-02	1,16E-02	1,14E-02	1,14E-02
Oleksandrivske Reservoir	^{3}H	1,40E+01	1,53E+01	1,40E+01	1,40E+01
	^{90}Sr	2,42E-02	2,59E-02	2,42E-02	2,42E-02
	^{134}Cs	6,90E-03	7,51E-03	6,90E-03	6,90E-03
	^{137}Cs	9,30E-03	9,80E-03	9,30E-03	9,30E-03

Table 2.

Maximum concentrations of radionuclides in water (C^{i}) of water bodies for the period 1991-2020, Bq/l

Reservoir	^{137}Cs	^{134}Cs	^{90}Sr	^{54}Mn	^{108m}Ag	^{110m}Ag	$^{103,106}Ru$	^{57}Co	^{60}Co	^{3}H
Tashlyk Reservoir	0,20	0,10	0,10	0,05	1,12	0,8	0,1	0,09	0,15	270
Oleksandrivske Reservoir	0,09	0,10	0,10	–	–	–	–	–	–	60

The content of radionuclides in the bottom sediments of the reservoirs is shown in Table 3.

Table 3.

Radionuclides content in sediments, Bq/kg

Reservoir	^{90}Sr		^{137}Cs		^{134}Cs		^{60}Co		^{54}Mn	
	2017 year	2021 year	2017 year	2021 year	2017 year	2021 year	2017 year	2021 year	2017 year	2021 year
Tashlyk Reservoir	2,90	3,62	5,39	4,8	0,90	0,29	0,51	0,65	0,39	0,42
Oleksandrivske Reservoir	4,18	4,19	1,07	0,65	0,75	0,62	0,52	0,44	0,37	0,74

The tables show that the content of radionuclides in the sediments has changed. Based on the data from the previous tables, the accumulation coefficients of radionuclides in sediments were calculated and presented in Tables 4 and 5.

Table 4.

Accumulation coefficients of radionuclides by sediments $k^{i}_{bottom}, \frac{Bk/_{kg}}{Bk/_{l}}$

Reservoir	2013 year		2014 year		2017 year		2021 year	
	^{137}Cs	^{134}Cs	^{137}Cs	^{134}Cs	^{137}Cs	^{134}Cs	^{137}Cs	^{134}Cs
Tashlyk Reservoir	38	33	40	32	44	30	50	28
Oleksandrivske Reservoir	94	51	77	56	82	68	82	59

Based on the data of Tables 2 and 3, the accumulation coefficients of radionuclides by sediments were calculated and presented in Table 5.

Table 5.

Accumulation coefficients of radionuclides by sediments k^{i}_{bottom} , $\frac{Bk/_{kg}}{Bk/_{l}}$

Reservoir	^{90}Sr	^{54}Mn	^{108m}Ag, ^{110m}Ag	^{103}Ru, ^{106}Ru	^{57}Co, ^{60}Co
Tashlyk Reservoir	150	250	580	430	420
Oleksandrivske Reservoir	120	320	600	420	400
Average value by reservoirs	135±35	270±50	590±20	425±10	410 ±10

Figure 1 shows a graphical comparison of the chemical composition of the Tashlyk and Oleksandrivske reservoirs. There is a difference between the Tashlyk and Oleksandrivske reservoirs in terms of a number of hydrochemical parameters. As can be seen, the Tashlyk Reservoir, in particular due to its higher water temperature (average value of 12.1 ± 2.2 ^{0}C) compared to the temperature regime of the Oleksandrivske Reservoir (average value of 7.8 ± 1.1 ^{0}C), is characterised by higher pH and alkalinity values throughout the year:

– for the Tashlyk Reservoir, the hydrogen pH varied from 8.4 to 9.2 units, and for the Oleksandrivske Reservoir, the pH varied from 8.3 to 8.4 units, the difference was 10%;

– for the Tashlyk Reservoir, the alkalinity was in the range of 20-25 mg-eq/l, and for the Oleksandrivske Reservoir, the alkalinity was in the range of 5.2-5.7 mg-eq/l, the difference was up to 5 times.

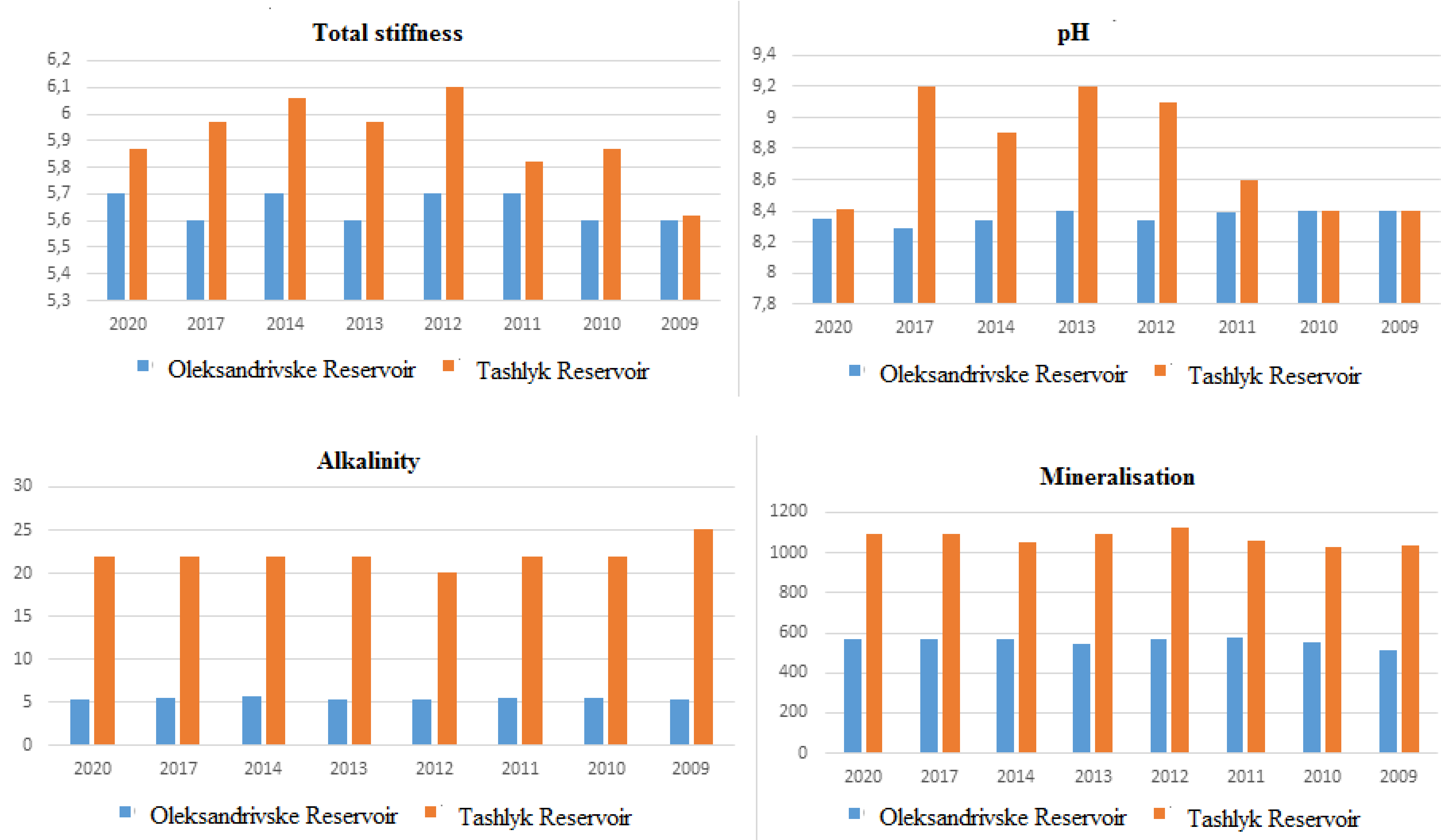

Fig. 1. Comparative analysis of hydrochemical parameters of Tashlyk and Oleksandrivske reservoirs

There is also a significant difference between the values of total hardness and dry residue for these reservoirs. Thus, for the Oleksandrivske reservoir, the dry residue of water samples averaged 572±12 mg/l, while for the Tashlyk reservoir it was 1100±57 mg/l. As you know, dry residual water is an indicator that characterises the amount of dissolved substances, primarily mineral salts, in 1 litre of water. This parameter determines the total amount of mineral inorganic salts of calcium, magnesium, potassium, sodium, heavy metals dissolved in water, as well as a large percentage of organic substances. This parameter is used primarily to determine the overall mineralisation of water. In other words, the waters of the Tashlyk Reservoir are highly mineralised. This usually prevents the accumulation of toxicants, including radioactive ones, by the biota of the reservoir ecosystem, and thus will prevent the deposition of these toxicants by the reservoir sediments.

This explains the lower values of ^{137}Cs and ^{134}Cs accumulation coefficients in the bottom sediments of the Tashlyk Reservoir compared to the corresponding values of the Oleksandrivka Reservoir (see Tables 4, 5).

The relationship between water salinity (dry residue) and the values of ^{137}Cs and ^{134}Cs accumulation coefficients in the bottom sediments of the Tashlyk and Oleksandrivske reservoirs was analyzed (Fig. 2). The results showed a linear relationship (r = 0.98), and the regression equation with a determination coefficient $R^2 = 0.92$, is as follows:

$$k_{\text{bottom}}^{\text{Cs}} = -10{,}179C + 101{,}43$$

$k_{\text{bottom}}^{\text{Cs}}$ – is the coefficient of cesium radioisotopes accumulation by bottom sediments; C is the dry water residue, mg/l.

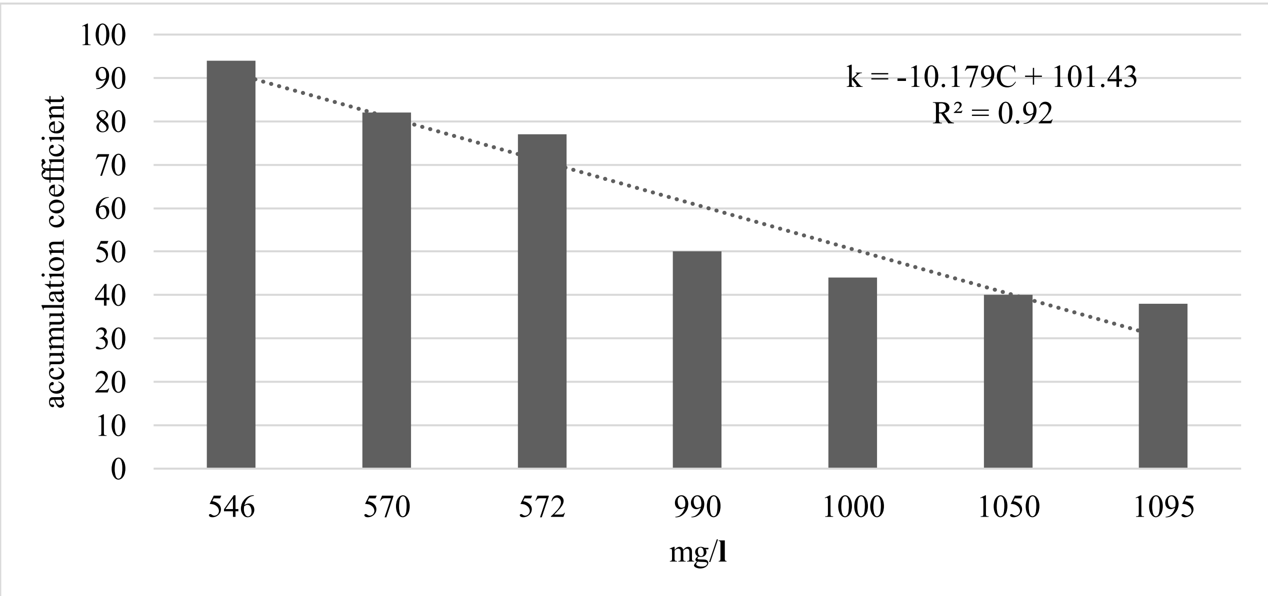

Fig. 2. Relationship between water salinity (dry residual) and ^{137}Cs and ^{134}Cs accumulation coefficients in the bottom sediments of the Tashlyk and Oleksandrivske reservoirs

The presence of dissolved oxygen in water is an important factor that significantly affects the processes of water quality formation and the state of aquatic ecosystems. Determining the oxygen regime of surface waters is an important component of assessing the state of aquatic ecosystems and catchment areas. The concentration of dissolved oxygen in water is one of the main integral indicators that characterize the quality of surface water as one of the most valuable natural resources. The participation of oxygen in the processes of biological, chemical, physical and mechanical self-purification of water bodies indicates that the assessment of dissolved oxygen concentration is of great practical and general scientific importance. Oxygen plays an important role not only in maintaining existing life forms in various water bodies, but also in the transformation of substances that enter surface waters with wastewater from urbanized and industrial areas, as well as with runoff from agricultural and livestock complexes. In recent years, due to increased anthropogenic pressure, the oxygen regime of many rivers, reservoirs, canals and lakes in Ukraine has become increasingly stressed, with the frequency and duration of frost events increasing, and a significant amount of dissolved oxygen being consumed by the decomposition (destruction) of easily oxidized organic substances. The concentration of dissolved oxygen in water is one of the most important hydrochemical parameters that determines the intensity of redox biochemical processes in water bodies. Therefore, the oxygen regime and the oxygen content in water and its dynamics are often taken as an integral indicator of the state of aquatic ecosystems and water quality in them.

For these reservoirs, there is also a difference between the dissolved oxygen in the water of the reservoirs (Fig. 3). In our opinion, this also affects the processes of accumulation and retention of radionuclides by the bottom sediments of the reservoirs, which also justifies lower values of these coefficients for the Tashlyk Reservoir compared to the Oleksandrivske Reservoir.

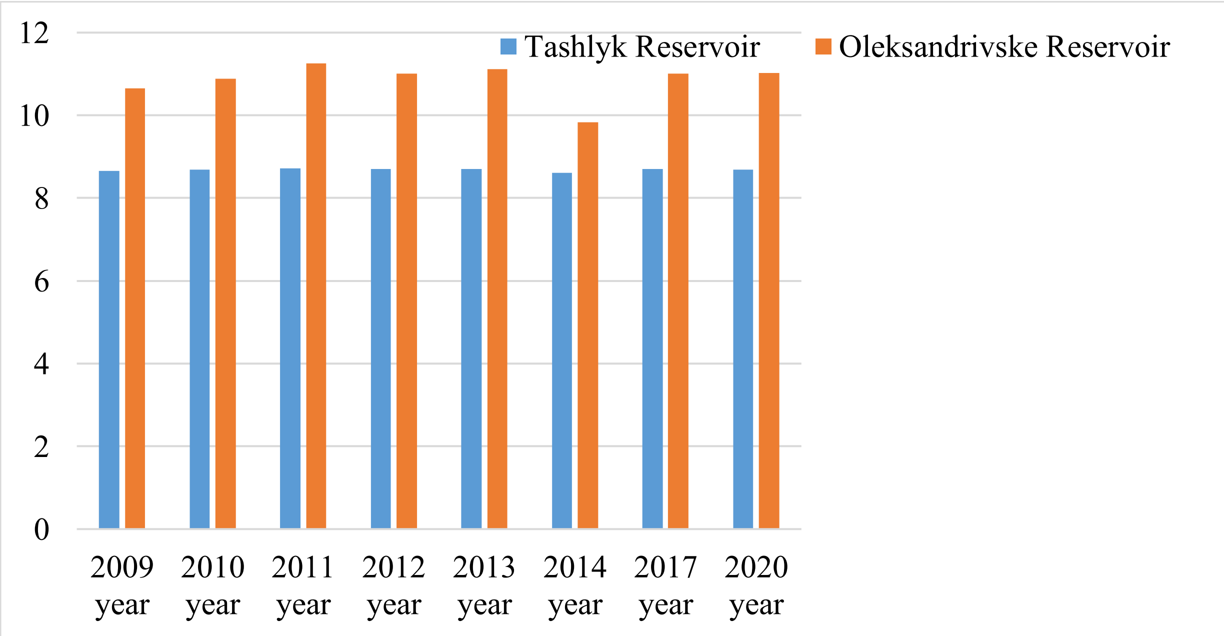

Fig. 3. Difference between the level of dissolved oxygen in the water of Tashlyk and Oleksandrivske reservoirs

Conclusions. The accumulation coefficients of ^{137}Cs (38±5 $\frac{Bk/kg}{Bk/l}$), ^{134}Cs (36±8 $\frac{Bk/kg}{Bk/l}$) are 2.5 times lower than the corresponding accumulation coefficients for the Oleksandrivka Reservoir (78±5 $\frac{Bk/kg}{Bk/l}$, 72±7 $\frac{Bk/kg}{Bk/l}$ for ^{137}Cs and ^{134}Cs, respectively). This may indicate a gradual loss of the accumulation capacity of sediments to retain radiocaesium.

The difference between the Tashlyk and Oleksandrivske reservoirs was established by a number of hydrochemical parameters:

–by temperature: the Tashlyk Reservoir is characterised by a higher average annual water temperature (12.1 ± 2.2 ^{0}C) compared to the temperature regime of the Oleksandrivske Reservoir (7.8 ± 1.1 ^{0}C);

– in terms of hydrogen pH: for the Tashlyk reservoir, the pH level (8.3-8.4 units) is 10% lower than for the Oleksandrivske reservoir (8.4-9.2 units);

–in terms of alkalinity: for the Tashlyk reservoir, the alkalinity is 5 times higher (20-25 mg-eq/l) than for the Oleksandrivske reservoir (5.2-5.7 mg-eq/l),

–on the dry residue (total mineralisation) of water: for the Tashlyk Reservoir, the dry residue (1100±57 mg/l) is 2 times higher than for the Oleksandrivske Reservoir (572±12 mg/l);

–for dissolved oxygen in the water of the reservoirs: in the Tashlyk reservoir, this indicator is 10-20% lower than in the Oleksandrivske reservoir.

These differences between the hydrochemical differences between the Tashlyk and Oleksandrivske reservoirs determine significantly lower coefficients of radionuclide accumulation by the bottom sediments of the Tashlyk reservoir. Thus, in particular, the presence of an inverse linear relationship (r=-0.98) between water salinity (dry residual) and the values of ^{137}Cs and ^{134}Cs accumulation coefficients in the sediments of the Tashlyk and Oleksandrivske reservoirs was established, and a regression equation (R^2=0.92) was determined that allows estimating the coefficient of accumulation of cesium radioisotopes in sediments depending on water salinity.

References:

1. Grygorieva, L., Tomilin, Y. (2009) Formation of radiation load per person in the south of Ukraine: factors, forecasting, countermeasures: Monograph. 332 p. . Ukr.
2. Kutlakhmedov, Y., Korogodin, V., Kutlakhmedova-Vyshnyakova, V. (1997) Radiocapacity of Ecosystems. J. Radioecol. 5 (1). – 25–35. Ukr.
3. Kuzmenko, M., Gudkov, D., Kireev, S. (2010). Man-made radionuclides in freshwater ecosystems. K., Naukova Dumka, 261 p. Ukr.
4. Povinec, P., Pham, M., Sanchez-Cabeza, J. (2007). Reference material for radionuclides in sediment IAEA-384 (Fangataufa Lagoonsediment). Journal of Radioanalytical and Nuclear Chemistry. 273(2), 383-393. Ukr.
5. Safety justification for the lifetime extension of the South-Ukrainian NPP power units beyond the design life (2015): Non-Technical Summary. Report of the Energoatom Company. 82 c. Ukr.