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Radionuclides in the Ecosystem of Lake Tygish in the Zone of the Eastern Ural Radioactive Trace

A. V. Trapeznikov, P. I. Yushkov, V. N. Nikolkin, V. N. Trapeznikova, M. Ya. Chebotina, and A. A. Ekidin

Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia

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Abstract—The radioecological situation in Lake Tygish is described. The lake is situated on the central axis of the Eastern Ural Radioactive Trace (EURT), which was formed after the nuclear accident in the Southern Urals in 1957. The distributions of ^{90}Sr and ^{137}Cs among the main components of the water body and the results of the measurement of tritium concentration in the water are presented. Mathematical models are described that have made it possible to estimate changes in the concentrations of radionuclides and their amounts accumulated in the water and bottom sediments of the lake during the long period after the accident and to predict the development of the radioecological situation in the lake until 2057. Based on the mathematical models, more accurate data on the initial ecological situation in the lake in the year of the accident have been obtained.

Key words: radionuclides, Eastern Ural Radioactive Trace, water body, water, bottom sediments, aquatic plants, fish, accumulation coefficients.

The nuclear accident at the Mayak Production Association in 1957 resulted in the radioactive contamination of a large area and the formation of the Eastern Ural radioactive trace (EURT) in the Chelyabinsk, Sverdlovsk, and Tyumen' oblasts. Its total area was more than 23000 km^2. The total fallout from the radioactive cloud consisting of liquid and solid aerosol particles was about 74 PBq (*Kompleksnaya ekologicheskaya otsenka…*, 1993; Bol'shakov *et al.*, 1994; *Vostochno-Ural'skii radioaktivnyi sled*, 1996).

Various natural ecosystems, including lakes, were contaminated with radionuclides. Lake Tygish in the Sverdlovsk oblast is one of them. Three years after the accident, the amounts of ^{90}Sr accumulated in the water, bottom sediments, and plant and animal biomass were 2.2, 20, and 0.27 Ci (77.7, 790, and 10 GBq), respectively (*Itogi izucheniya…*, 1990). Later, the region of the EURT was additionally contaminated because of the wind transfer of radioactive silt from the shore of Lake Karachai (near the Mayak Production Association) in 1967 and radionuclides from the zone of the Chernobyl accident in 1986.

In 1993, the Department of Continental Ecology (DCE) of the Institute of Plant and Animal Ecology (Ural Division, Russian Academy of Sciences) studied the radioecological situation in Lake Tygish. By that time, more than 35 years had passed since the accident, and it could be expected that the original contamination pattern had changed due to natural radioactive decay, nuclear accidents in 1967 and 1986, and redistribution of radionuclides in the environment because of various migration processes.

OBJECTS AND METHODS

Lake Tygish is situated in the Kamenskii region, on the central axis of the EURT, approximately 105–110 km away from the site of the accident (Fig. 1). It is a body of fresh standing water with an area of 6.7 km^2; mean and maximum depths of 2.0 and 3.5 m, respectively; and a water volume of 13.4×10^9 l (Galaktionov, 1990; *Itogi izucheniya…*, 1990). The lake is in the zone affected by the gas and aerosol discharges from the industries located in the city of Kamensk-Ural'skii. After the accident in 1957, the inhabitants of the village located on the coast of Lake Tygish were evacuated, the village itself was obliterated, and the coasts were decontaminated. The control Lake Shchuch'e is located outside the EURT, 30 km northwest of Lake Tygish.

P.V. Okunev studied and described the bottom sediments of the lake (*Radioekologicheskoe issledovanie…*, 1992); radioecological characteristics of the catchment area were published earlier (*Pochvenno-ekologicheskie usloviya…*, 1996; Aarkrog *et al.*, 1992; Karavaeva *et al.*, 1994).

To assay ^{90}Sr and ^{137}Cs in the water, we took 200-l water samples into aluminum flasks (the sampling was made in duplicate or triplicate), acidified them, and transported them to the laboratory. The water was filtered and evaporated, and the dry residue was ashed at 450°C. To assay tritium, 1-l water samples were taken

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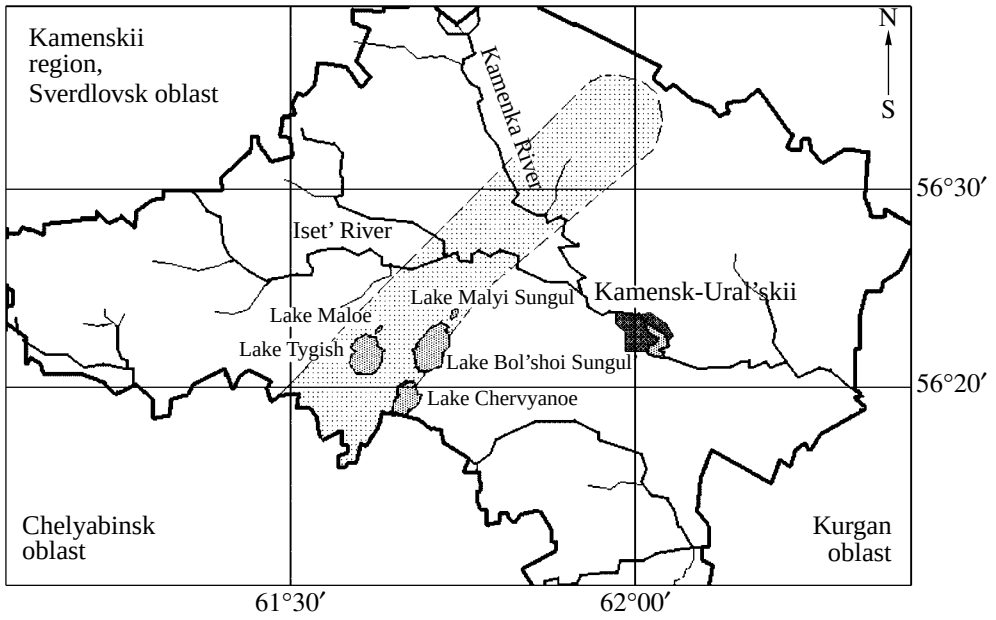

Fig. 1. Geographic location of Lake Tygish in the Kamenskii region, Sverdlovsk oblast. The boundary of the EURT is shown by a dashed line.

into glass vessels in duplicate. The water was filtered, distilled, and tritium-enriched by the one-step electrolysis method (Chirkova, 1974). Plants (3–5 kg fresh weight) were sampled in triplicate from different parts of the lake, cleansed of mud, air-dried, and ashed in an oven at 450°C. Fish were caught with nets; the samples (3–5 kg fresh weight) were prepared in triplicate. Eviscerated fish carcasses were dried and ashed at 450°C.

Bottom sediments were sampled in winter (from ice) at 20 points (Fig. 2). The samples were taken layer by layer with the use of a sampler specially designed by V.N. Aleksashenko (DCE, Institute of Plant and Animal Ecology) for this study. The sampler allowed us to take samples of sapropel from a specified depth, avoiding admixture of material from other layers of the bottom ground. Sapropel was sampled at 5-, 20-, and 50-cm intervals at depths of less than 20, 20–100, and 100–350 cm, respectively. The samples of bottom sediments were dried, grounded, and sifted through a sieve with a mesh size of 1 mm. The amount of ^{90}Sr in the samples was determined by the radiochemical method from the amount of the daughter element, ^{90}Y. The radiometry of ^{90}Y was performed in an UMF-1500 low-background device equipped with an SBT-13 end-window counter; the counting error was 15%. The concentration of ^{137}Cs was measured using an AM-A-02-F1 multichannel analyzer with a Limon-type NaJ(T1) detector with a 150×100 mm crystal; the mean counting error was 20%. The radiometry of tritium samples was performed by the liquid scintillation method using a Delta-300 device; the counting error was 5%.

MATHEMATICAL MODELS

The data obtained during studies in the natural ecosystem, together with published data of other authors (*Vostochno-Ural'skii radioaktivnyi sled*, 1996) became the basis of mathematical models that were then used to describe the changes in the concentrations and total amounts of radionuclides accumulated in the water and bottom sediments of the lake and to predict their contents in different components of the lake in the period until 2057.

When calculating the concentrations and amounts of radionuclides in the components of Lake Tygish at a given moment of time, we took into account their natural radioactive decay according to the formula

$$C_t = C_0 \exp(-\lambda t) = C_0 \exp(-t \ln 2/\tau_{1/2}). \quad (1)$$

As a first approximation, the dependence of changes in the concentrations and amounts of each radionuclide in the components of the lake on the time elapsed since the moment of the accident may be written in a similar exponential form:

$$C_t = C_0 \exp(-kt), \quad (2)$$

$$Q_t = C_t V = C_0 V \exp(-kt) = Q_0 \exp(-kt), \quad (3)$$

where t is the time (years) after the moment of the accident; C_0 and Q_0 are the initial concentration and total content, respectively, of the radionuclide in the water of the lake at the moment of the accident; C_t and Q_t are the concentration and total content, respectively, of the radionuclide at moment t; λ is the decay constant related to the half-life of the radionuclide ($\tau_{1/2}$) as follows: $\lambda = \ln 2/\tau_{1/2}$; and k is the constant determining the

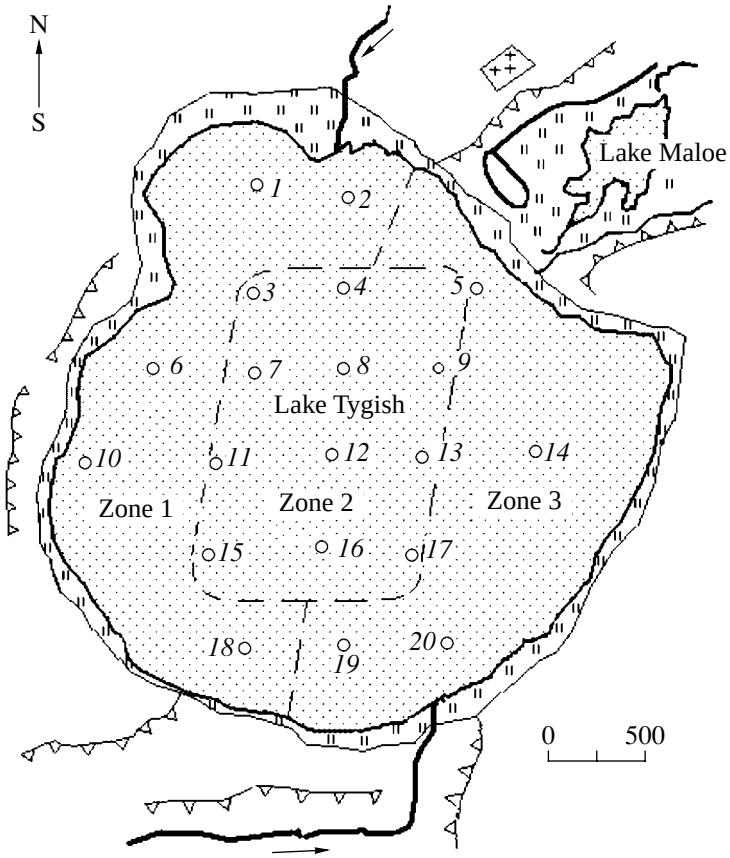

Fig. 2. The map of sampling of bottom sediments from Lake Tygish.

rate of time-dependent change in the radionuclide concentration (the exponential decrement). In the general case, the constant k should exceed the decay constant λ because of radionuclide transfer from water into bottom sediments; hence, the decrease of radioactivity in water is more rapid than that accounted for by natural radioactive decay alone.

We used the experimental data characterizing the decrease in radionuclide concentrations in the water of Lake Tygish to construct the concentration kinetic curves and to obtain the corresponding regression equations of type (2). Extrapolating these relationships to the moment $t = 0$, we determined the initial concentrations of radionuclides (C_0) in the water immediately after its primary contamination resulting from the nuclear accident. The total amount of radionuclides in the lake (Q_0) was calculated by multiplying the initial concentration (C_0) by the volume of water (V). Using the calculated C_0 and Q_0 and correcting for the radioactive decay, we calculated, by Eqs. (2) and (3), the current concentrations and total amounts of radionuclides in the water for different moments over a period of 100 years after the accident.

The amount of radionuclides in bottom sediments was determined by different methods. First, we calculated it as the difference between their amounts in water calculated from the expected concentration (taking into account the natural decay) and the amounts calculated from the actual concentrations at a given moment:

$$Q_{bs} = Q_0[\exp(-\lambda t) - \exp(-kt)], \quad (4)$$

where Q_{bs} is the amount of radionuclides in bottom sediments.

Second, we calculated the amount of radionuclides by summing the results of direct measurements in different bottom layers. In this case, we additionally estimated the total amounts of ^{90}Sr and ^{137}Cs in the ground with the use of mathematical simulation. We described the dependences of the concentrations of radionuclides on the depth of sediments by decreasing exponential functions of type (5):

$$C_x = b\exp(-ax), \quad (5)$$

where x is the vertical coordinate (m); C_x is the volume concentration of the radionuclide at the depth x (Bq/m^3); and a and b are parametric constants, the former determining the decrement of the function of the radionuclide vertical distribution (decreasing with depth), and the latter being formally equal to the surface concentration of radionuclide ($C_x = b$ at $x = 0$).

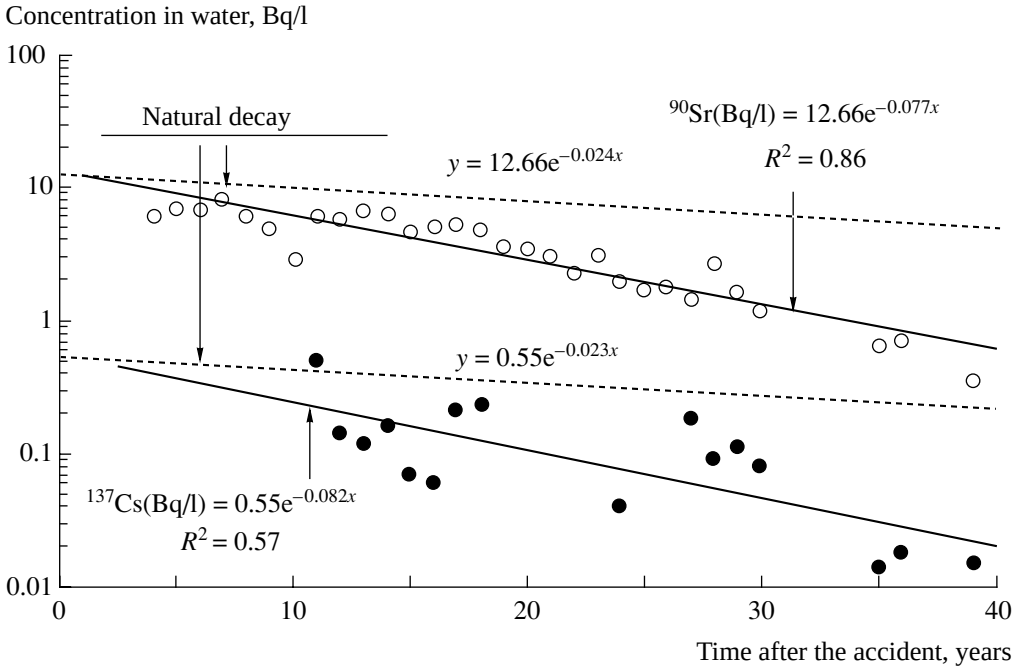

Fig. 3. Changes in ^{90}Sr and ^{137}Cs concentrations in the water of Lake Tygish in the period from 1957 to 1997.

Integrating the above functions from zero to the maximum depth (h_{max}) and taking into account the lake bottom surface (S), we calculated the amounts of radionuclides in bottom sediments:

$$Q = S\int_0^{h_{max}} be^{-ax}dx. \quad (6)$$

The vertical distribution of radionuclides in the bottom sediments of Lake Tygish was described by two different exponential equations for the upper and lower segments of the vertical profile. After the integration of the functions for two depth ranges corresponding to two segments of the profile, we summated them and obtained the total amounts of radionuclides in bottom sediments:

$$Q = S\left(\int_0^{h_1} b_1e^{-a_1x}dx + \int_{h_1}^{h_{max}} b_2e^{-a_2x}dx\right), \quad (7)$$

where h_1 is the arbitrary boundary between the two segments of the vertical profile determined by graphical analysis of experimental data (m) and h_{max} is the maximum depth of occurrence of bottom sediments (m).

Summing up the amounts of radionuclides in water and bottom-sediment samples calculated by Eqs. (3) and (7), respectively, we obtained the total contents of ^{90}Sr and ^{137}Cs in the lake in 1993. Then, we calculated the amounts of radionuclides in the lake for specified moments (t) in the interval from 0 to 100 years after the accident, taking into account the natural decay of the radionuclides:

$$\sum Q_t = \sum Q_{1993}\exp[-\ln 2(t-36)/\tau_{1/2}]. \quad (8)$$

When constructing the model, we made the following assumptions: (1) the outflow of radionuclides from the lake and the secondary contamination of the lake from the catchment area are negligible, and (2) the amounts of radionuclides in plant and animal biomass are substantially lower than their amounts in water and bottom sediments.

RESULTS AND DISCUSSION

The studies performed in Lake Tygish in 1993 showed that the concentrations of ^{3}H, ^{90}Sr, and ^{137}Cs in the water were 12.3, 0.6, and 0.01 Bq/kg, respectively, which is lower than the allowable concentrations for potable water (*Normy radiatsionnoi bezopasnosti NRB-99*, 1999). The concentration of ^{90}Sr was approximately six times higher than that in the control Lake Shchuch'e (0.10 Bq/kg), whereas the concentrations of ^{137}Cs and ^{3}H in the water of both lakes were practically the same.

To calculate the primary influx of ^{90}Sr and ^{137}Cs into the ecosystem of Lake Tygish, we calculated the dynamics of the changes in radionuclide concentrations in the water over a period of 40 years after the accident (Fig. 3). We determined the following regressions of the concentrations of these radionuclides on time:

$$^{90}\text{Sr(Bq/l)} = 12.66\exp(-0.077t), \quad R^2 = 0.86; \quad (9)$$

$$^{137}\text{Cs(Bq/l)} = 0.55\exp(-0.076t), \quad R = 0.57. \quad (10)$$

Table 1. Calculated amounts of ^{90}Sr and ^{137}Cs in the water and bottom sediments of Lake Tygish

Parameter	Year									
	1957	1967	1977	1987	1993	1997	2007	2017	2037	2057
Time after the accident, years	0	10	20	30	36	40	50	60	80	100
^{90}Sr concentration in water calculated by Eq. (1) taking into account radioactive decay, Bq/l	12.7	9.9	7.8	6.1	5.3	4.8	3.8	3.0	1.8	1.1
Amount of ^{90}Sr in water calculated by Eq. (3) taking into account radioactive decay, GBq	169.6	133.1	104.5	82.0	70.9	64.3	50.5	39.6	24.4	15.0
^{90}Sr concentration in water calculated by regression equation [Eq. (10)]	12.7	5.9	2.7	1.3	0.8	0.6	0.3	0.13	0.03	0.006
Amount of ^{90}Sr in water calculated by regression equation, GBq	169.6	78.8	36.6	17.0	10.7	7.9	3.7	1.7	0.4	0.1
Amount of ^{90}Sr in bottom sediments calculated by Eq. (4), GBq	0.0	54.3	67.9	65.0	60.2	56.4	46.8	37.9	24.0	15.0
^{137}Cs concentration in water calculated by Eq. (1) taking into account radioactive decay, Bq/l	0.6	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1
Amount of ^{137}Cs in water calculated by Eq. (3) taking into account radioactive decay, GBq	7.3	5.8	4.6	3.7	3.2	2.9	2.3	1.8	1.2	0.7
^{137}Cs concentration in water calculated by regression equation [Eq. (11)], Bq/l	0.6	0.2	0.11	0.05	0.03	0.02	0.01	0.006	0.0008	0.0001
Amount of ^{137}Cs in water calculated by regression equation, GBq	7.3	3.2	1.4	0.6	0.4	0.3	0.12	0.05	0.010	0.002
Amount of ^{137}Cs in bottom sediments calculated by Eq. (4), GBq	0.0	2.6	3.2	3.1	2.8	2.6	2.2	1.8	1.2	0.7
The ^{90}Sr-to-^{137}Cs concentration ratio in water calculated taking into account radioactive decay	23.2	22.9	22.6	22.4	22.2	22.1	21.8	21.5	21.0	20.5
The ^{90}Sr-to-^{137}Cs concentration ratio in water calculated by regression equations	23.2	24.6	26.0	27.5	28.4	29.0	30.7	32.5	36.3	40.6
The ^{90}Sr-to-^{137}Cs concentration ratio in bottom sediments calculated by Eq. (4)	–	20.9	21.2	21.3	21.4	21.4	21.3	21.2	20.9	20.4

Hereinafter, R^2 is the determination coefficient, or the square of the correlation coefficient. It follows from these equations that, at the moment of the accident ($t = 0$), the concentrations of ^{90}Sr and ^{137}Cs in the water of the lake were 12.7 and 0.55 Bq/l, respectively. This corresponds to a primary influx of 169.6 and 7.3 GBq of ^{90}Sr and ^{137}Cs, respectively, into the lake.

Table 1 shows the amounts of radionuclides in the main components of Lake Tygish at different times after the accident, calculated from the results of the analysis of their water concentration dynamics. According to our model, the water of Lake Tygish in 1993 contained 10.7 and 0.38 GBq of ^{90}Sr and ^{137}Cs, respectively, and its bottom sediments contained 60.2 and 2.8 GBq of ^{90}Sr and ^{137}Cs, respectively.

The study of the vertical and spatial distributions of ^{90}Sr and ^{137}Cs in the bottom sediments of Lake Tygish in 1993 was performed by the layer summation method. The radioactive contamination of bottom sediments varied in different parts of the lake (Table 2). For example, the concentrations of both radionuclides studied were higher in the second (central) zone of the lake.

The vertical distribution of radionuclides was adequately described by two exponents corresponding to different parts of the profile, i.e., different depths (Fig. 4). We calculated the amounts of ^{90}Sr and ^{137}Cs in the bottom sediments of Lake Tygish in 1993 from the results of direct measurements and from the results of mathematical simulation. The two methods yielded similar results: the amounts of ^{90}Sr determined by the two methods were 66.9 and 79.3 GBq and those of ^{137}Cs were 14.3 and 14.9 GBq, respectively. Remember that our earlier estimate of the amount of ^{90}Sr in the sapropel of this lake in 1993, which was based on the

Table 2. Vertical distribution of ^{90}Sr and ^{137}Cs in the bottom sediments of Lake Tygish in 1993, Bq/kg air-dry weight

Layer, cm	^{90}Sr			^{137}Cs			$^{90}Sr/^{137}Cs$		
	Zone								
	1	2	3	1	2	3	1	2	3
0–5	189 ± 50	369 ± 65	189 ± 58	38 ± 14	137 ± 48	49 ± 28	5.0	2.7	3.9
5–10	115 ± 59	304 ± 63	104 ± 25	14 ± 5	81 ± 13	29 ± 7	8.2	3.8	3.6
10–15	142 ± 80	365 ± 127	64 ± 18	21 ± 7	51 ± 25	26 ± 10	6.8	7.2	2.5
15–20	198 ± 114	245 ± 52	29 ± 4	12 ± 3	38 ± 20	17 ± 4	16.5	6.5	1.7
20–40	41 ± 14	113 ± 35	27 ± 2	16 ± 5	12 ± 5	14 ± 5	2.6	9.4	1.9
40–60	33 ± 16	74 ± 22	43 ± 21	13 ± 4	11 ± 5	13 ± 3	2.5	6.7	3.3
60–80	34 ± 15	43 ± 10	26 ± 12	16 ± 5	15 ± 5	7 ± 0.6	2.1	2.9	3.7
80–100	19 ± 10	59 ± 14	10 ± 5	12 ± 5	13 ± 6	3 ± 1	1.6	4.5	3.3
100–150	17 ± 1	72 ± 18		6 ± 1	9 ± 2		2.8	8.0	
150–200	14 ± 5	70 ± 15		7 ± 2	7 ± 2		2.0	10.0	
200–250	11 ± 4	50 ± 12		6 ± 0.5	5 ± 1		1.8	10.0	
250–300	12 ± 10	59 ± 20		3 ± 1	4 ± 1.7		4.0	14.8	
300–350	4 ± 0.8	20 ± 2		1 ± 0.4			4.0		

Table 3. Total amounts of ^{90}Sr and ^{137}Cs in the bottom sediments of Lake Tygish in 1993 calculated by layer summation, GBq

Layer, cm	^{90}Sr					^{137}Cs					$^{90}Sr/^{137}Cs$
	Zone			Sum by layers	%	Zone			Sum by layers	%	
	1	2	3			1	2	3			
0–5	1.7	3.3	1.7	6.7	8.4	0.3	1.2	0.4	2.0	13.4	3.35
0–10	1.0	2.7	0.9	4.7	5.9	0.1	0.7	0.3	1.1	7.4	4.27
10–20	1.3	3.3	0.6	5.1	6.4	0.2	0.5	0.2	0.9	5.9	5.67
15–20	1.8	2.2	0.3	4.2	5.3	0.1	0.3	0.2	0.6	4.0	7.00
20–40	1.5	4.0	1.0	6.5	8.2	0.6	0.4	0.5	1.5	10.0	4.33
40–60	1.2	2.6	1.5	5.4	6.8	0.5	0.4	0.5	1.3	8.8	4.15
60–80	1.2	1.5	0.9	3.7	4.6	0.6	0.5	0.3	1.4	9.1	2.64
80–100	0.7	2.1	0.4	3.1	4.0	0.4	0.5	0.1	1.0	6.7	3.10
100–150	1.5	6.4	0.0	7.9	10.0	0.5	0.8	0.0	1.3	9.0	6.08
150–200	1.3	6.3	0.0	7.5	9.5	0.6	0.6	0.0	1.3	8.4	5.77
200–250	1.0	4.5	0.0	5.4	6.9	0.5	0.4	0.0	1.0	6.6	5.40
250–300	1.2	5.9	0.0	7.1	9.0	0.3	0.4	0.0	0.7	4.7	10.14
300–350	0.4	2.0	0.0	2.4	3.0	0.1	0.0	0.0	0.1	0.7	24.00
250–350	1.6	7.9	0.0	9.5	12.0	0.4	0.4	0.0	0.8	5.4	11.88
Total	17.3	54.8	7.2	79.3	100.0	5.3	7.2	2.4	14.9	100.0	5.32

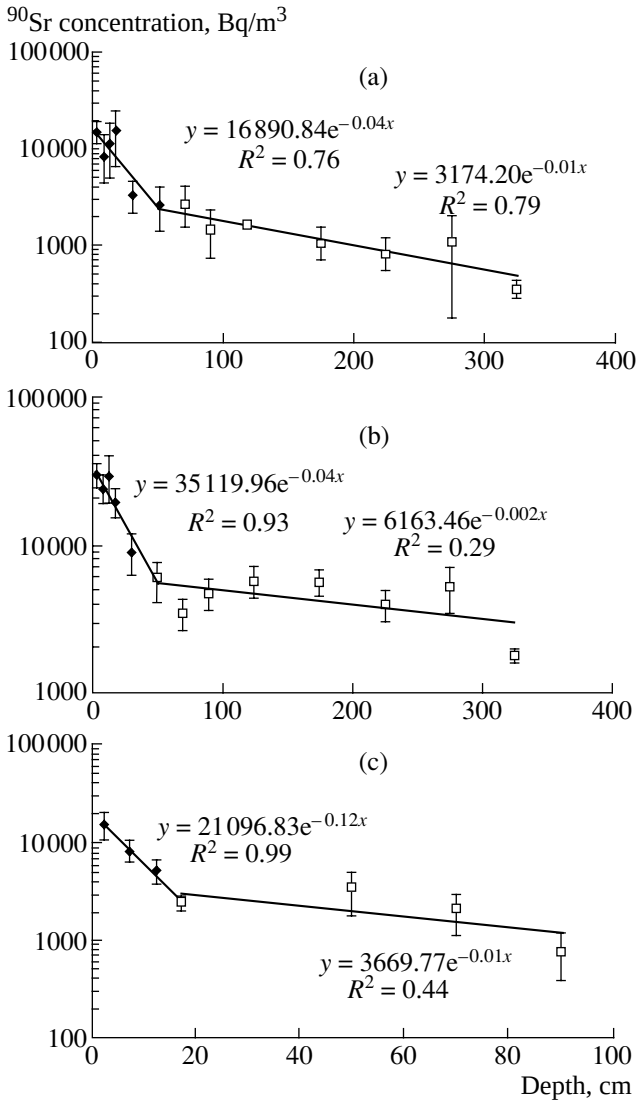

Fig. 4. Vertical distribution of ^{90}Sr in the bottom sediments of Lake Tygish in zones (a) 1, (b) 2, and (c) 3.

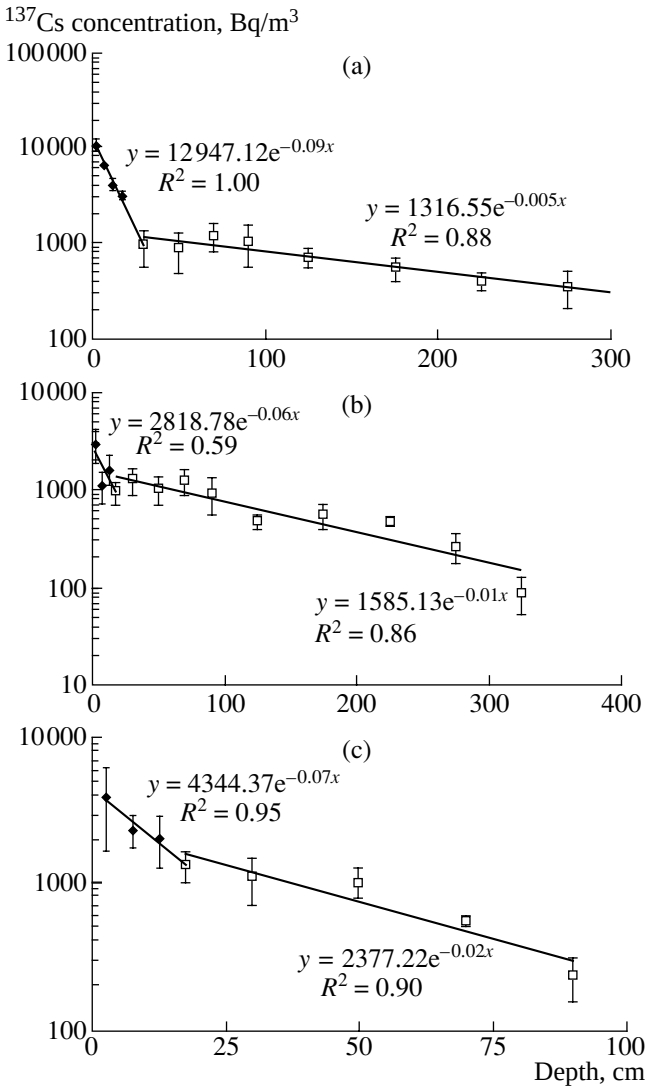

Fig. 5. Vertical distribution of ^{137}Cs in the bottom sediments of Lake Tygish in zones (a) 1, (b) 2, and (c) 3.

analysis of water samples, was close to that obtained from direct measurements in sapropel samples, whereas these values for ^{137}Cs differed from each other by about five times. In our opinion, this discrepancy was accounted for by the considerably lower ^{137}Cs concentration, compared to the ^{90}Sr concentration, in the lake. Therefore, the measurement error for ^{137}Cs was higher. A fivefold difference should not be regarded as substantial in the case of such calculations by different methods; the estimates obtained may be considered fairly close to each other.

We used the results of our estimations to perform a retrospective analysis of the influx of radionuclides into the lake as a result of the nuclear accident in 1957. Taking into account radioactive decay, the total amounts of ^{90}Sr and ^{137}Cs were 160 and 33.5 GBq, respectively. These data considerably differ from the data reported by other authors (*Itogi izucheniya…*, 1990), who estimated, e.g., the amount of ^{90}Sr in the lake in 1957 at 988 GBq, i.e., almost six times higher than our estimate. Since the method of calculation is not indicated in the cited work, it may be presumed that the estimation was performed by extrapolating the data on contamination density in the catchment area in 1960 (4 Ci/km^2, which corresponds to 148 GBq/km^2) to the lake. Apparently, the considerable unevenness of the land surface (the presence of woody and herbaceous vegetation, elements of microrelief, buildings, etc.), compared to the surface of the water body, determined the high retention of radioactive material there.

The ^{137}Cs content was determined in plants sampled from the lake. The concentrations of the radionuclide were the highest in submerged plants, such as *Cladophora*, Charophyta, and *Myriophyllum* (22–39 Bq/kg

dry weight). Plants growing in water close to the shore (cattail and rush) contained 2–5 Bq/kg of ^{137}Cs. The accumulation coefficients (ACs) of submerged plants, cattail, and rush were 2190–3940, 510, and 230 units, respectively. The concentrations of ^{90}Sr and ^{137}Cs in the shells of pond snails collected near the northern coast of Lake Tygish were 4.4 kBq/kg and 45 Bq/kg dry weight, and the ACs were 7330 and 4500, respectively. In the bodies of crucian carp (without viscera), the content of ^{90}Sr was 120–250 Bq/kg wet weight, which exceeded the maximum allowable content for edible fish (100 Bq/kg) according to the regulations in force (*Sanitarnye pravila*, 1999). The concentration of ^{137}Cs in the fish was lower than the maximum allowable value (the latter is 130 Bq/kg).

Our calculations demonstrated (Table 3) that 80 to 90% of ^{90}Sr and ^{137}Cs in the lake were contained in bottom deposits. This may be explained by the fact that Charophyta accounted for a large proportion of the lake vegetation and, apparently, made a considerable contribution to the formation of sapropel. This is confirmed by the results of our studies performed in Lake Bol'shoe Miassovo (Il'menskii Nature Reserve, the southern Urals) in 1974–1977. According to these data, Charophyta are characterized by high ACs for both radionuclides (especially ^{90}Sr), and sapropel under their mats are rich in these radionuclides (Kulikov and Chebotina, 1988).

The areal and vertical distribution patterns of the radionuclides in the lake strongly depend on several factors determining the migration of matter in this water body. ^{90}Sr and ^{137}Cs may serve as the tracers of the migration of biogenic and abiogenic matter and the formation of bottom sediments, because their primary distribution and, especially, subsequent redistribution among the main components of the lake reflect the characteristics of these processes. The radionuclides that enter the lake are included into the biogeochemical cycles that are characteristic of this water body and determine the type of bottom sediments and the chemical composition of water. The amounts and routes of the liquid and solid runoffs (including plant debris and the carcasses of dead animals) are largely determined by the meso- and microrelief, soil, and plant cover of the coastal portion of the catchment area. In addition, the distribution of radionuclides in bottom sediments is strongly affected by aggregations of aquatic plants and animals (e.g., mollusks, which are numerous on plants) and the movement of water masses driven by the wind. As Lake Tygish is shallow, water masses transfer the upper layers of low-density sapropel to bottom depressions.

The concentrations of radionuclides in rainwater were estimated in the early 1960s (Shvedov *et al.*, 1962). According to these data, the ^{90}Sr-to-^{137}Cs ratio in rainwater is 0.6. The ratio between the amounts of these radionuclides was more than 20 in the water of Lake Tygish and varied from 1.6 to 16.5 in the bottom sediments. Thus, ^{90}Sr that has entered the water body after the accident at the Mayak Production Association in 1957 remains the main radioactive contaminator of the ecosystem of Lake Tygish.

The aforementioned prognoses of the further development of the radioecological situation in Lake Tygish indicate the possibility of commercial use of its sapropel in the near future, provided the lake is not subjected to additional radioactive contamination.

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