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A HISTORICAL OUTLINE OF RADIONUCLIDE CONTAMINATION OF THE YENISEY FLOODPLAIN BASED ON LANDSCAPE AND RADIOMETRIC SURVEY

ABSTRACT. Distribution of technogenic radionuclides discharged by the Krasnoyarsk Mining and Chemical Combine (KMCC, Zheleznogorsk) in the period from 1958 to 1992 has been studied in floodplain landscapes of the Yenisey river. After shutting down the direct-flow reactors the radioactive contamination of the Yenisey river became dozen times lower. Performed landscape and radiometric studies revealed factors responsible for radionuclide differentiation and the character of radionuclide distribution within two landscape segments of the Yenisey river floodplain. The first segment characterized the impact zone from 16 km to 20 downstream the discharge, the second one was studied in the remote zone as far as 2000 km down the river. Artificial radionuclide contamination was most intensive in the 60-ies of the past century when it reached the Kara Sea. Traces of that contamination were registered in soils of both sites at the depth of 20–50 cm.

KEY WORDS: radionuclides, landscape, floodplain, Yenisey River, Krasnoyarsk MCC.

INTRODUCTION

In the period from 1958 to 1992 an operation of the Krasnoyarsk Mining and Chemical Combine (KMCC) located in the town of Zheleznogorsk 40 km downstream the city of Krasnoyarsk led to radionuclide contamination of the water and bottom and floodplain sediments of the Yenisey river mainly with ^{137}Cs, ^{60}Co, ^{152}Eu, ^{154}Eu over long distances downstream the discharge of radioactive elements [Vakulovsky et. al., 1995]. After shutting down of the two direct-flow reactors in 1992 the amount of radionuclide discharge to the Yenisey river dropped dozen times and radioecological situation improved.

The systematic radioecological studies of the Yenisey river which included the analysis of radionuclide contamination of water, bottom sediments and the coastal floodplain date back to the year of 1972 [Vakulovsky et. al., 2008]. Then for the first time they discovered radioisotopes of the reactor origin (^{65}Zn и ^{137}Cs) in the bottom sediments of the Yenisey mouth. The studies performed by SPA "Typhoon" within the large river segment stretching from KMCC to port Dudinka at the beginning of the Yenisey delta revealed considerable radionuclide contamination of the floodplain soils [Vakulovsky, 2008]. The levels of ^{137}Cs and ^{60}Co 48 km downstream the discharge equaled to 230 kBq/m^2 and 47 kBq/m^2, and 409 km downstream – 34 kBq/m^2 and 19 kBq/m^2 correspondingly.

As far as 1655 km away from the discharge the contamination by ^{137}Cs and ^{60}Co dropped sharply down to 21 kBq/m^2 and 0,37 kBq/m^2. One should note that at the beginning of 70-ies the global level of ^{137}Cs was 2,5 kBq/m^2 [Kvasnikova et. al., 2000].

However these studies were kept secret at that time and known only to a narrow group of specialists. The results of the further expeditions organized by SPA "Typhoon" in 70-ies were unknown until the beginning of 90-ies when after the Chernobyl accident the data on radionuclide contamination of the area of the former USSR were declassified and the independent radioecological studies of the Yenisey floodplain became available. Since that time there began massive studies of distribution of technogenic radionuclides in the Yenisey basin.

STUDIED AREA, MATERIALS AND METHODS

The fist scope of data on radioecological situation in the Yenisey river food plain based on field sampling was published in 90-ies of the last century [Kuznetsov et. al., 1994; 1999; Vakulovski et. al., 1995; Nosov et. al., 1993; Nosov, 1996; Linnik et. al., 2000; Sukhorukov et. al., 2004]. A review of some part of these data was done in the frame of the projects launched by Green Cross Russia. The main goal of these projects was the data organization as a geo-informaiton system (GIS) covering all the available sources of information on radionuclide contamination of the environment in areas of location of the nuclear-fuel operating plants. The Yenisey floodplain section from the KMCC down to practically its lower reaches and discharge to the Kara Sea was among the objects under [Linnik et. al., 2001].

The map of radionuclide contamination of the Yenisey floodplain was constructed during preliminary works on a set of maps for the Atlas of radionuclide contamination of Russia in areas of the plants producing weapon plutonium [Izrael et. al., 2000]. In framework of the program on mapping the areas with technogenic radionuclide contamination an air-gamma survey of the Yenisey floodplain was carried out in 1993 that revealed the longest in the FSU belt of ^{137}Cs contamination stretching for 2000 km from KMCC to port Dudinka [Kvasnikova et. al., 2000].

The second stage of radioecological studies in the Yenisey basin started in 90-ies in frame of series of international and regional projects including complex expeditions.

The presented work is based on materials obtained during field work supported by two international COPERNICUS projects: the STREAM (near impact zone of KMCC) and ESTABLISH (the distant zone) performed in the years of 2000, and 2001–2002, field studies in the upper delta of Yenisey were organized by the Vernadsky Institute of the Russian Academy of Sciences in cooperation with the Moscow State University. The data on radionuclide contamination included both the published and archival materials.

The main goal of the work was to analyze the landscape structure, relief, the soil and vegetation cover, composition of the river sediments and to reveal landscape peculiarities of distribution of ^{137}Cs, ^{60}Co, $^{152,154}Eu$ in the impact area of the KMCC. The most contaminated low-and medium-level floodplain of the river was the first object to study. Plots located on terraces or the adjacent watersheds were used for local data on global technogenic radionuclide fallout.

To determine contamination density and radionuclide distribution in soil profiles standard soil sampling in increments was applied with due regard to river sediment lithology. In the near KMCC impact zone the radioecological studies included field gamma-spectrometry measurements with the help of collimated detector CORAD. To measure depth distribution in floodplain soils in field conditions a radiometer with dip detector was used. The main principles of evaluation of technogenic radionuclide concentration with the help of the CORAD device applied to landscape-radiation investigation of the Yenisey floodplain were published in [Linnik et. al., 2005; 2006].

Radiometric measurements enabled to optimize the sampling mode and to select the most representative plots. However, this approach appeared to be applicable in case of contamination level exceeding 10 kBq/m^2. At the lower level the error of detection considerably increased and in the lower Yenisey area the sampling was based on landscape geochemical structure and the suggested conditions of technogenic radionuclide deposition [Korobova et al, 2002, 2007, 2009].

RESULTS

Peculiarities of the Yenisey hydrological regime in the period of radionuclide contamination

Radionuclide transport and concentration with the Yenisey waters depend in general upon its hydrological regime. The discharged radionuclides actively migrate with water masses contaminating bottom sediments and floodplain soils in the high water periods. The Yenisey water flow considerably increases after the river confluence with its right tributary – the Angara River. The mean annual discharge of the Yenisey River equals to 2864 m^3/s (hydrological station Bazaikha), while that of the Angara river amounts to 4518 m^3/s [Lammers and Shiklomanov, 2006]. As a result the concentration of radionuclides in the contaminated Yenisey waters considerably reduces after the confluence. The next significant dilution of the main stream water takes place after the confluence with the river of Podkamennaya Tunguska in the middle reaches of Yenisey. Here the annual Yenisey discharge reaches 10769 m^3/s (gauge station Podkamennaya Tunguska). It continues to increase in the lower reaches up to 18395 m^3/s (hydrological station at port Igarka). Such dilutions considerably lessen radionuclide concentration in river water.

The main radionuclide contamination of the Yenisey basin occurred in the years of 1966, 1972 and 1988 abound in water. The high water period of 1966 was maximum and the longest. The high-water events of 1972 and 1988 succeeded the construction of the Krasnoyarsk hydroelectric power station in 1970 which changed the Yenisey hydrological regime in such a way that since then the high floodplain within the river segment from KMCC down to the Yenisey confluence with the Angara river has never been flooded any more and the period of the middle floodplain flooding has shortened. However, deposition of sediments contaminated by radionuclides continued in the lower floodplain areas. The influence of the Krasnoyarsk HPP on the main stream water abundance in the middle Yenisey was leveled due to its tributaries. However the high water levels of 1972 and 1988 could be followed not only in the upper Yenisey section (Bazaikha) but in its middle part also (Podkamennaya Tunguska). This could have resulted in similar character of technogenic radionuclide distribution on different levels of the river floodplain landscapes. In the lower Yenisey reaches high water periods do not coincide with those registered at the two indicated gauge stations. For example, in August 1988 the Igarka station did not register high water in Yenisey unlike the upstream stations. Therefore one should not expect synchronized radionuclide deposition in the upper-middle and the lower Yenisey sections.

Analysis of the results of some previous studies concerning KMCC impact on the Yenisey floodplain contamination

The air-gamma survey of the Yenisey basin in 1993 has recorded radionuclide contamination of its floodplain section 1760 km long stretching from Zheleznogorsk to Dudinka along both its right and left bank zones (Fig. 1). The results of this air-gamma survey demonstrate the scale of contamination and some difference between the coastal zones: the mean and maximum ^{137}Cs contamination levels of the left bank

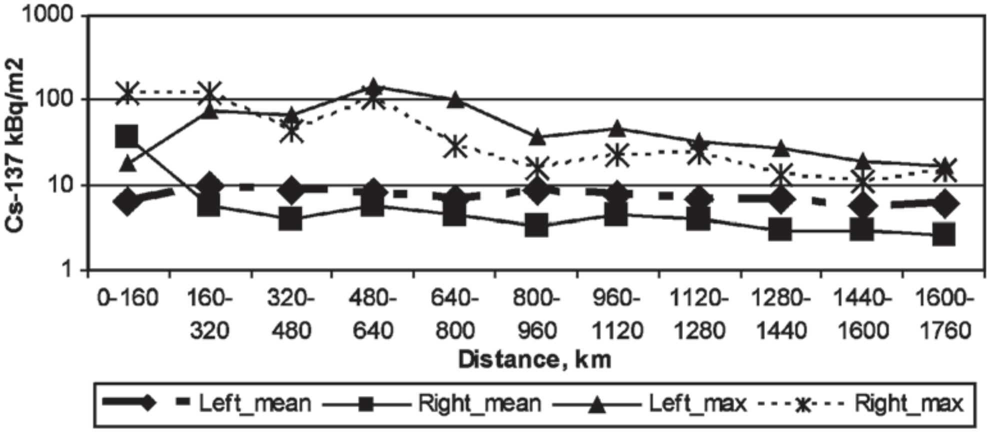


Fig. 1. Results of air-gamma survey of the Yenisey river floodplain performed in 1993 [Kvasnikova et. al., 2000].
Left_mean – mean values of ^{137}Cs activity (kBq/m^2) along the Yenisey left bank; Right_mean – the same for the right bank; Left_max – maximum values of ^{137}Cs activity (kBq/m^2) along the Yenisey left bank; Right_max – the same for the right bank

floodplain were noticeably higher than those of the right one except for the near impact zone within 160 km downstream the KMCC which is located on the right bank of the river. ^{137}Cs contamination considerably exceeded its global levels varying in the interval of 1,7–2,5 kBq/m^2 [Kvasnikova et. al., 2000; Sukhorukov et. al., 2004].

In the remote zone of Yenisey contamination the average value of ^{137}Cs activity varied from 2,9 kBq/m^2 to 6 kBq/m^2 with similar maximum values several times exceeding the global level. In the near zone maximum ^{137}Cs contamination of the left bank zone equaled to 18 kBq/m^2, while on the right bank it reached 122 kBq/m^2. The next zone with high ^{137}Cs contamination density was observed on the left bank 480–640 km and 640–800 km downstream, where the maximum values amounted to 144 kBq/m^2 and 100 kBq/m^2 correspondingly. The existence of high radioactive contamination of the middle section of the Yenisey basin falling downstream was found also by the other investigators. The measurements performed at two river stations located 166 km (the first one) and 784 km (the second one) downstream the KMCC by [Vakulovsky et. al., 2008] in summer period of 1979 showed the following levels for ^{152}Eu ^{137}Cs, ^{60}Co: the 1st station – 6 Bq/m^3, 8,7 Bq/m^{3}and 10 Bq/m^3; the 2nd station – 2 Bq/m^3,2 4,6 Bq/m^{3}and 4,1 Bq/m^3. This means that as far as 784 km downstream the discharge point there was a 2–3-fold decrease of radioactivity of a set of radionuclides corresponding to the 2,9 increase of the total river discharge within this distance interval. A relatively high and variable portion of ^{152}Eu ^{137}Cs and ^{60}Co radioisotopes migrating in suspended particles (0,6, 0,5, 0,93 of total unit 166 km downstream and 0,8, 0,5 and 0,6 784 away correspondingly), led to different modes and levels of contamination of the floodplain soils by various radionuclides during deposition of the suspension.

High level of technogenic contamination of the bottom river sediments and the soils in the middle Yenisey segment before the reactors were shut down was also registered in 1991 by A. Nosov [Nosov et. al., 1993]. For example, the activity of ^{137}Cs and ^{60}Co measured by him in the Belij island 510 km downstream the discharge point reached 53–78 and 20––63 kBq/m^2. In vertical soil profile two peaks corresponding to the soil surface and the depth interval of 30 to 40 cm were found, both being of practically similar activity. This is a cogent argumentation in favour of the two stages of the major contamination of the Yenisey basin. The first peak dating back to 60-ies of the past century was marked by radionuclide contamination of the buried alluvial layers while the second one found in the surface soil layer was formed due to the contaminated high water in the year of 1988.

Results of the studies in the near KMCC impact zone

The near KMCC impact zone embraces the areas 16–20 km downstream the discharge point of technogenic radionuclides. The investigated part of the floodplain included the Island of Beriozovy measured with the help of radiometer CORAD along three landscape transects (BP-0, BP-1, BP-2), and a plot Balchug (BP-4) 20 km downstream the discharge point. Cross-section BP-0 was located at the head of the island. It started from the Balchug branch and crossed the low, low medium and high level floodplain (Fig. 2). One should note that at the mainstream side both the low and medium levels were practically absent and passed abruptly into the high floodplain. In general the same asymmetric morphological structure is typical for whole island of Beriozovy. Cross-sections BP-1 and BP-2 being 105 m and 160 m long started also at the Bulchug flow parth, crossed the low and medium floodplain and reached the high level floodplain. Following the levels of radionuclide contamination measured along the BP-0 cross-section one could see their relation to peculiarities of morphology of the island floodplain (Fig. 2).

The Balchug floodplain massif had a more complicated landscape structure which was reflected in a larger variation of the inventory of technogenic radionuclides corresponding to its different landscape parts [Linnik et. al., 2005; Linnik, 2011]. Landscape complexes of the Balchug area were composed of the island part 350–400 m wide attached to the right bank of the Balchug branch. The coastal zone had a flat or wavy flat surface dissected by the narrow (10–20 m wide) flow paths which dried out when the current water level dropped below 1 m over the mean low water one. The length of Balchug cross-section equaled to 460 m and contained 48 measurement points. Statistical parameters of radionuclide distribution in the areas studied in the near impact zone are presented in Table 1.

As the global ^{137}Cs contamination within the near KMCC impact zone equaled to 1,75 kBq/m^2 [Sukhorukov et. al., 2004] the data of Table 1 demonstrated that almost the whole area under study was subjected to radionuclide contamination. The exception stood for the plots located in the high level floodplain of the Beriozovy Island at the highest elevation levels (over 6 m of altitude), where the ^{137}Cs contamination density was somewhat lower than the global one or was not registered at all. In general this floodplain segment was characterized by very high differentiation of ^{137}Cs contamination density within small distances.

The revealed zones of maximum accumulation of ^{137}Cs (up to 1000 kBq/m^2) were located

Table 1. Field data on 137Cs activity measured along cross-sections of the Yenisey floodplain in the KMCC near impact zone

Id	Distance from the discharge source (km)	Total number of measure-ment points	Maximum hight* (cm)	^{137}Cs activity (kBq/m^2)			
				Mean	Min	Max	St.dev.
BP-0	96	16	616	81,8	1,5	287	103,6
BP-1	96	8	324	129,1	24	251,6	77,3
BP-2	97	25	650	182,4	19,2	663,4	158
BP-4	100	48	563	183	9,6	1002	175,8

* Relative to water level at the time of survey in August 2000 (for BP-0 – August 1999).

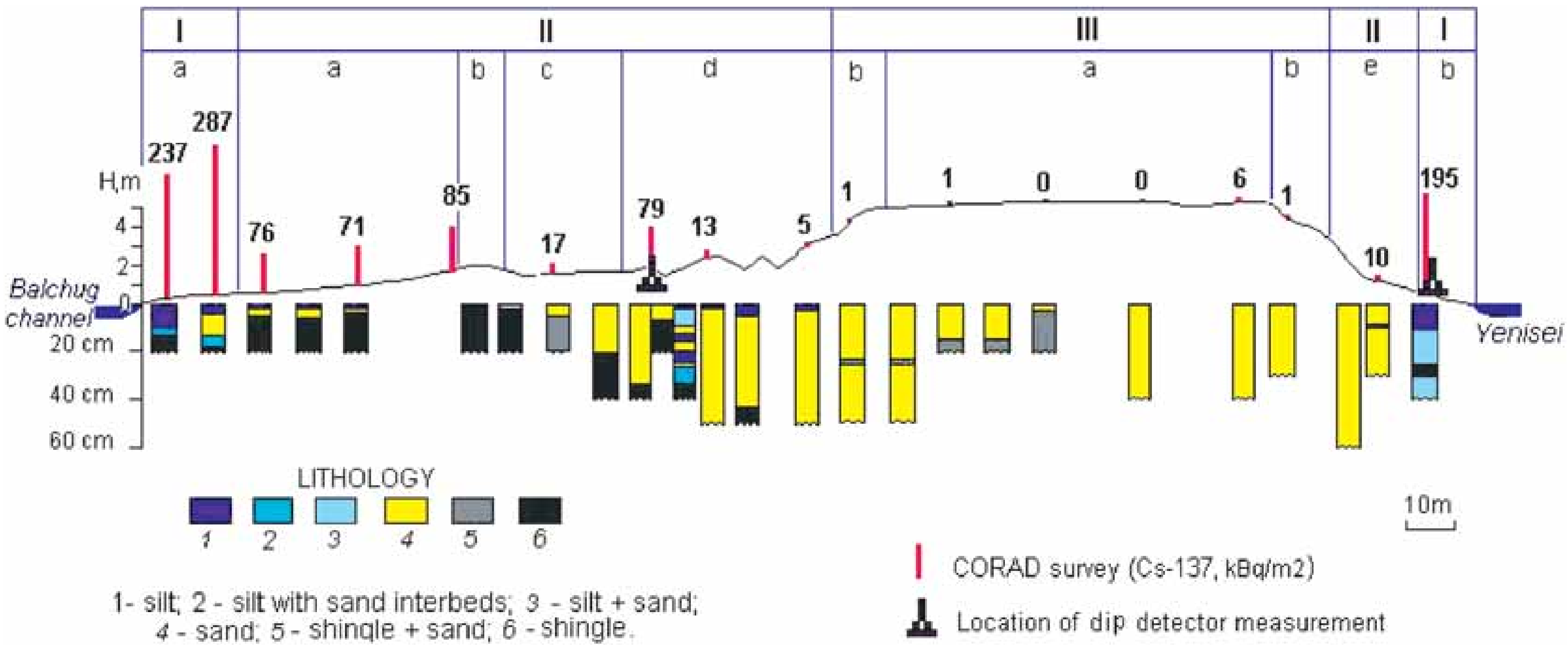


Fig. 2. ^{137}**Cs distribution along the landscape cross-section BP-0 (the Beriozovy Island)**

in the low floodplain composed of fine and small-grain sands with loamy interlayers at the bottom of the former flow paths now covered by a thin turf layer, and in depressions at the footslope of the middle-level floodplain where sandy-silt river load was deposited. The contamination density of ^{60}Co and $^{152,154}Eu$ in total reached the maximum value (190 kBq/m^2) also on the lower floodplain containing silt, peat and light loam deposits [Linnik et. al., 2005; Linnik, 2011].

The character of spatial distribution of radioactive contamination could be demonstrated by the measurements of 1999 performed along the landscape cross-section BP-0 located at the head of the Beriozovy Island (Fig. 2, [Linnik et. al., 2002]).

Landscape structure of this part of the Island Beriozovy included three elevation levels: the low, medium and high floodplain, which differed significantly in the density of ^{137}Cs contamination. Landscape cross-section BP-0 of the Beriozovy Island included 28 level and 16 field measurement points. At two locations (points #11 and #24) ^{137}Cs depth profile was measured with the help of the dip detector.

High water level (IIa is the basic floodplain surface, IIIb is the slope of the high bottom terrace) has been registered within the floodplain 4–5 m above the river water level. This section was formed by thick sandy series with particular horizons containing rare shingle and showed ^{137}Cs activity values below the sensitivity of the "CORAD" radio-spectrometer (1–6 kBq/m^2). Almost all the ^{137}Cs contamination here was concentrated in the lower level locations with maximum silt deposition. According to the "CORAD" field measurements the density of ^{137}Cs contamination of the low floodplain (Ia) varied from 195 to 287 kBq/m^2. Middle height floodplain level (Fig. 2, section II, a, b, c, d, e) was characterized by a more complicated composition of sediments that was reflected by variation of ^{137}Cs contamination density from 5 kBq/m^2 to 85 kBq/m^2.

Basing on measurement data at point 24 where the ^{137}Cs contamination density amounted to 195 kBq/m^2 the soil depth profile was sampled for the further laboratory analysis. The two clear depth maximum values of activity were found. They were suggested to be related to different periods of increase of radioactivity in river water due to release of the radionuclide waste from

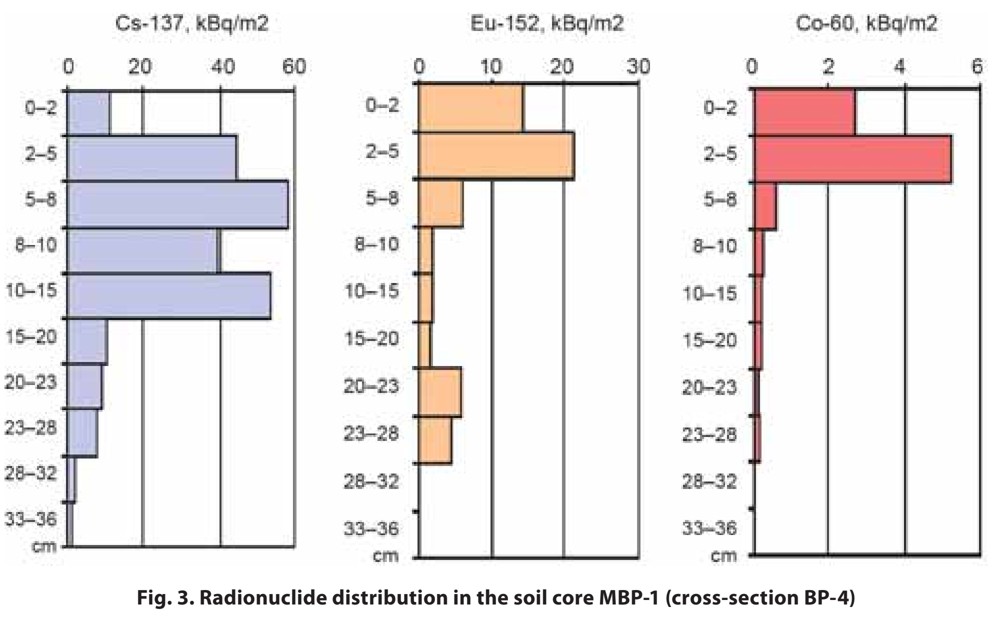


Fig. 3. Radionuclide distribution in the soil core MBP-1 (cross-section BP-4)

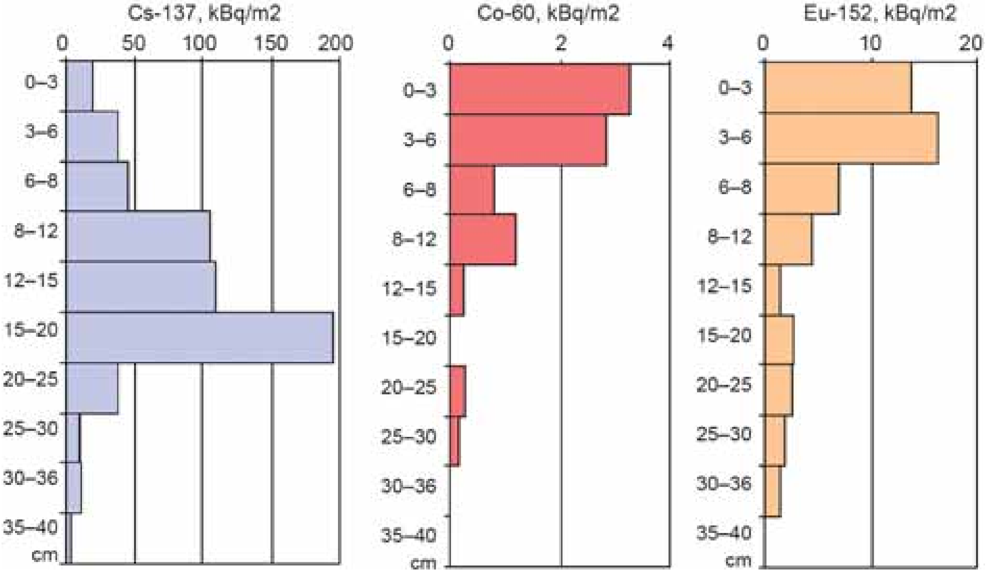


Fig. 4. Radionuclide distribution in the soil core MBP-2 (cross-section BP-4)

the Krasnoyarsk MCC. The first maximum of ^{137}Cs activity (630 Bq/kg) was found at the depth of 10–20 cm and corresponded to a sandy silt layer underlain by gley sand and silt, the second maximum activity (320 Bq/kg) was detected at the depth of 30–35 cm in the silty sand horizon. In the lower layers of the grey sand observed to 45 cm depth the activity dropped sharply to 23 Bq/kg.

The depth profile MBP-1 (Fig. 3) was located at the BP-4 cross-section of the Balchug massif and characterized the laminated alluvial sandy loam soil of the upper low-level hillock plot covered by the grazing meadow of forb-foxtail composition with birch and willow sprouts 2,13 m above the water mean level. The soddy silty sand at the top of the profile was succeeded by fine sands of laminated structure. There were two distinct peaks of radiocesium at the depth of 5–8 cm and 10–15 cm corresponding to the laminated sandy-loam horizons separated by a small radioactivity fall in the intermediate sandy layer. Both ^{152}Eu and ^{60}Co had maximum concentration in the top 2–6 cm layer showing fresh alluvium contamination at the indicated altitude.

Another depth profile at this cross section (MBP-2, Fig. 4) characterized the alluvial soddy sandy soil formed 3,19 m above the shoreline on top of the ridge of the medium-level floodplain under willow stand with bird-cherry trees and currant bushes. The soil core appeared to be contaminated by radiocesium twice as much. Maximum radiocesium inventory contained at the depth of 15–20 cm corresponded to the two thin humic gley loamy layers (Fig. 4). ^{60}Co concentration is half that being found in the soil profile MBP-1. This allowed suggesting the considerable earlier contamination of the ridge and its minor contamination during the later flooding processes since ^{60}Co and ^{152,154}Eu were found in the top layers.

High levels of ^{60}Co and ^{152,154}Eu activity in the surface soil layers supported the hypothesis of their possible contamination during high water in the year of 1988.

Results of the studies in the remote KMCC impact zone

Shown above the remote impact zone of KMCC stretched for more than 2000 km

Table 2. 137Cs contamination density of the soil depth layers within the lower Yenisey study plots [Korobova et.al., 2009]

Location, landscape	Profile index	Floodplain features	^{137}Cs inventory (kBq/m^2)		Elevation above water level (m)
			0–10 cm	0–50 cm	
Upper delta, island floodplain	PSH2-1	High level	1,02	2,20	12,00
	PSH2-8a	Slope	1,33	1,62	9,01
	PSH2-7***	Medium level	2,63	3,14	7,51
	PSH1-3	Low level ridge	3,72	88,10	3,21
	PSH1-1***	Low level depression	3,48	29,32	2,41
Middle delta, coastal floodplain	KR1-12*	Ridge	0,21	0,43	2,90
	KR1-15	Depression	1,50	5,72	3,48
	KR1-25**	Scar (terrace fragment)	0,37	1,60	4,58
Middle delta, island floodplain	TS1-4	Upper medium level, gentle slope	1,38	24,73	4,80
	TS1-8	Flattened medium-level	3,21	19,60	4,60
	TS2-7	Ridge top	0,33	1,53	6,03

Other maximum depths: *(0–75 cm), **(0–25 cm), ***(0–40 cm).

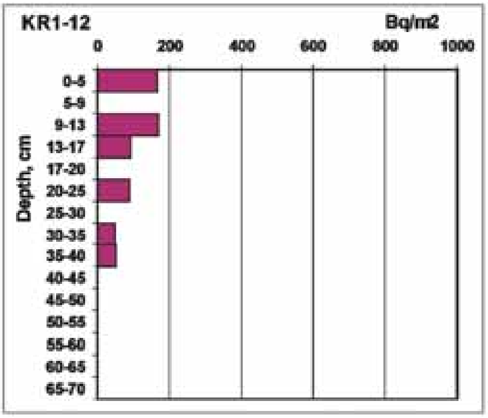
from the source of radionuclide discharge down the stream. Here we discuss the results obtained for three floodplain cross-sections characterizing: 1) the island floodplain in the upper Yenisey delta (the Pashkov Island situated opposite to set. Ust'-Port; 2) the right bank floodplain near set. Karaul and 3) the island floodplain in the central delta part (Island Tysyara). Basing on the data for the sampled soil cores and their relative elevation as presented in Table 2 one should note an indicative variation of ^{137}Cs contamination density of the Yenisey floodplain in the remote zone section.

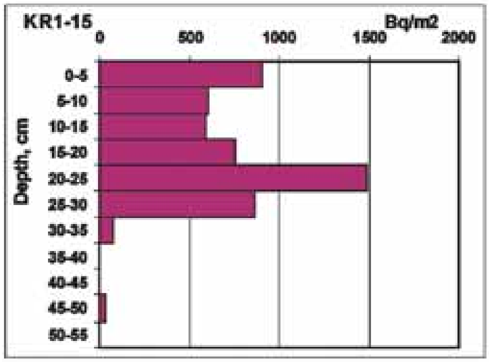
In general the radionuclide contamination in the lower Yenisey reaches unlike the upper parts was more descrete since the floodplain was subjected to washing out by a larger volume of water and radionuclide sedimentation and fixation was possible in landscape traps, e.g. plot KR1-15, where ^{137}Cs contamination equaled to 5,7 kBq/m^2.

Following this inference the plot KR1-12 with the contamination density 3–3,5 times lower the global value (Table 2) could have been more typical for the intensively washed floodplain areas in the lower reaches. The absence of the short-lived radionuclides of ^{60}Co and $^{152,154}Eu$ in the surface soil layer proved also the "old" age of the contamination event.

The vertical distribution of ^{137}Cs in the soil cores of right-side floodplain near set. Karaul exhibited different patterns. The riverside sandy ridge (KR1-12) had traces of contamination in some layers to a depth of 40 cm. The cores of the peat gley loamy soil taken in a hollow connecting the two thermokast depressions with lakes (KR1-15) and the higher-level soddy loamy sand soil (KR1-25) contained reliably detectable radioceasium quantities with maximum concentration at a depth of 20–25 cm corresponding to silty loam horizons rich in organic matter (Fig. 5).

The island food plain showed itself as a striking example of the relation between the events of radionuclide contamination, hydrological regime of the river and the structure of the river basin and floodplain. Maximum ^{137}Cs contamination reaching 88,1 kBq/m^2 was observed in the soil core of the plot PSH1-3 located on a low floodplain ridge at the head of the Pashkov Island situated





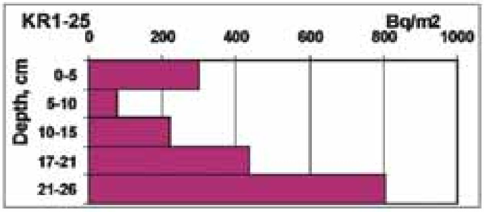
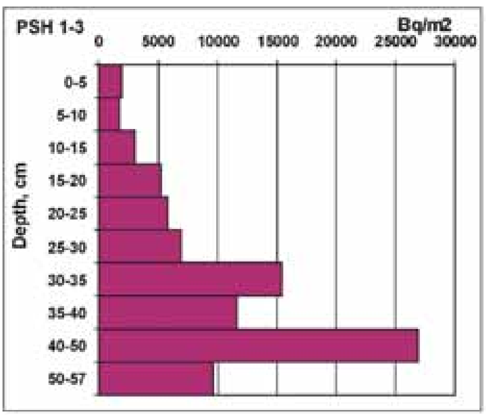
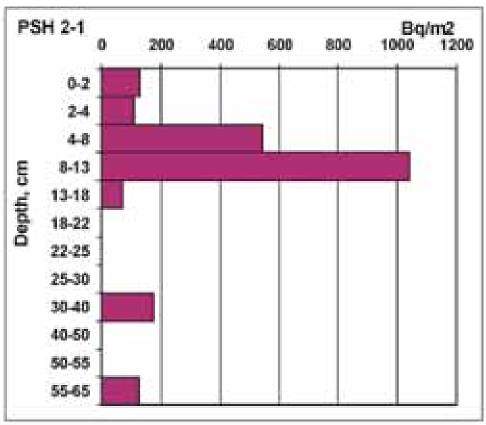


Fig. 5. ^{137}Cs and its contamination density vertical distribution in the floodplain and terrace cores sampled near set. Karaul





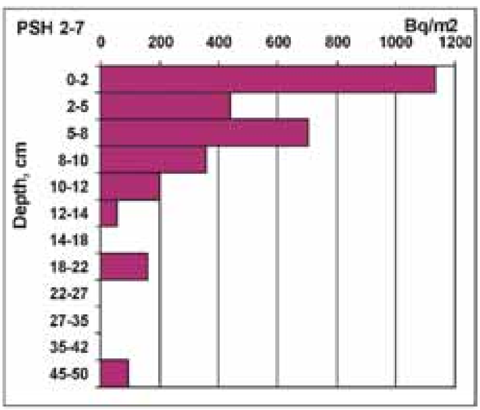
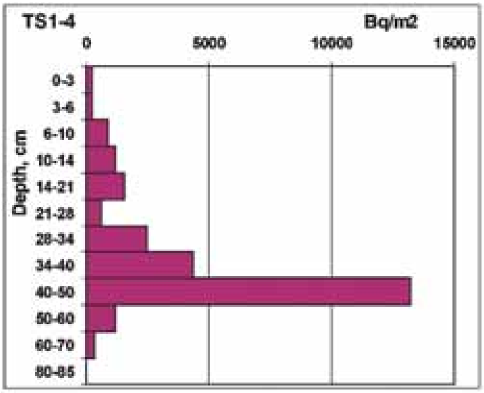
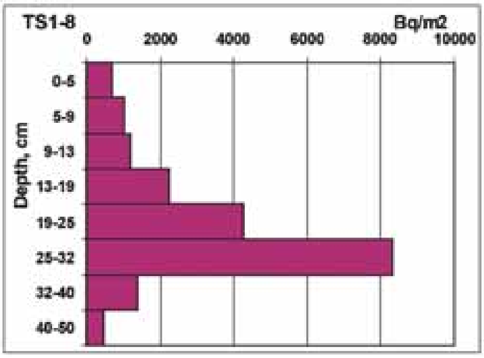


Fig. 6. Vertical distribution of ^{137}Cs the soil cores sampled on the Pashkov Island





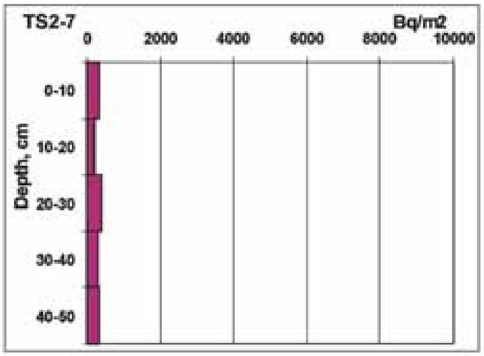


Fig. 7. ^{137}Cs and its contamination density vertical distribution in the soil cores sampled on the Tysyara Island

at the beginning of the Yenisey upper delta (Fig. 6). The density of ^{137}Cs contamination of the middle level (PSH2-7) and high level (PSH2-1) floodplain considerably decreased to 3,14 kBq/m^2 and 2,2 kBq/m^2 correspondingly that is only slightly higher than the global background value.

The location of maximum contamination at the depth of 40–50 cm proved its old age and its river origin. On the other hand, in case of the total low density of contamination and the maximum ^{137}Cs content in the surface soil layer observed on the middle and high floodplain showed domination of the aerial source of ^{137}Cs over the regional technogenic due to operation of the KMCC.

The plot studied on the other island floodplain (the Tysyara Island) also presented strong evidence of the old contamination of this island and a much lower contamination of this location in the subsequent periods of flooding. The two soil cores TS2-4 and TS2-8 located at different elevation levels had evident buried peaks of ^{137}Cs activity at the depth of 40–50 cm and 25–32 cm indicating considerable contamination event which could be related to radionuclide discharge during high water of 1966 (Fig. 7).

No clear traces of the 1988 discharge were observed. The upper soil layers down to 6 cm referred to river deposition after 1992 when the reactors were shut down. The activity of ^{137}Cs in these layers was close to that of the soils core located on the high level floodplain TS2-7. The low contamination of the latter core taken on the ridge top (1,53 kBq/m^2) and an even vertical distribution of ^{137}Cs corresponded to the pattern of river distribution of the global ^{137}Cs fallout rather than of the KMCC radionuclide discharge.

CONCLUSIONS

Modern structure of radionuclide contamination of the Yenisey floodplain landscapes depends upon a complex of different factors. A durable and unstable release of radionuclides to the flooding areas due to irregular KMCC discharges matched with different hydrological regimes of the Yenisey river and a complicated morphological structure of the floodplain landscapes has produced an exclusively complicated pattern of radioactive contamination of the Yenisey floodplain in both the spatial and temporal manifestation.

The near KMCC impact zone is characterized by a continuous contamination the middle and low-level floodplain while contamination of the remote zone was local. In general maximum of radionuclide load has been deposited in the low floodplain locations with domination of silty, peat and light loam deposits. In the near and middle impact zones of KMCC the radionuclide traces have indicated two events of maximum contamination related to discharges during high water in the years of 1966 and 1988 while in the remote zone a single event of enhanced contamination was found that presumably corresponded to radionuclide dumping in 1966.

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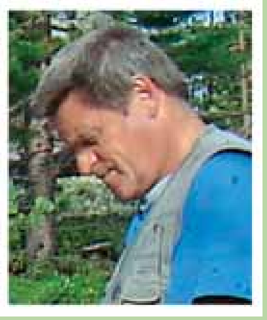

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