

Radionuclide contamination in the Syrdarya river basin of Kazakhstan

Results of the Navruz Project

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(Received April 6, 2004)

The results of radioecological investigations in the Syrdarya river basin in the Republic of Kazakhstan are presented. The work was carried out under the International Navruz Project. Nuclear activation analysis, X-ray fluorescence, and γ -spectrometry were used to measure the element and radionuclide (^{137}Cs , ^{40}K and ^{238}U , ^{235}U , and ^{232}Th families) compositions of soil, water, bottom sediments and vegetation. Samples were collected at 15 control points in Kazakhstan along the Syrdarya river and its inflows during four expeditions (autumn 2000 and 2001, spring 2001 and 2002).

Introduction

The Syrdarya river is the main life-supporting fresh water artery of South Kazakhstan. There is a high morbidity level among inhabitants of the region, and almost all medical indicators of health conditions of inhabitants, including children, are much lower than the average statistical ones for the Republic. One of the main reasons for high morbidity level in the region is the critical ecological and radio-ecological situation in the Syrdarya river basin.

One reason for this situation is the intensive agricultural activity with use of mineral (phosphate, potassium, and nitrate) fertilizers. Another is the contamination of water in Syrdarya river basin by domestic and industrial drains of large cities (Turkestan, Kentau, Kyzylorda, Baykonur and, especially, Shymkent). Further, the geochemical peculiarities of this region are reflected in water composition.

The most important and least studied peculiarity of this region is the presence of considerable uranium ore at Karatau ridge and its spurs and intensive industrial activity associated with its mining and processing. In addition, many uranium deposits are associated with deposits of carbonaceous, siliceous schist characterized by very high concentrations of rare and dispersed elements. Such elements as V, Cr, Co, As, Se, Hg, Th, and U, which have been shown to be hazardous to humans, are easily leached from these rocks by water. They can migrate in large amounts to the main Syrdarya stem, resulting in its contamination with radionuclides, heavy metals, and toxic elements. Uranium-related industrial activity, especially underground leaching, contributes to this process.

Figure 1 shows the main factors influencing the ecological situation in this region. It is necessary to note that all the circumstances mentioned above are endemic

not only to the basins of the Syrdarya and Amudarya rivers, but for the whole South Kazakhstan region and other countries of Central Asia as well. These factors were the impetus for beginning investigations of the amount and character of contamination of these river basins, on the territories of four countries of Central Asia.

The Navruz Project began in November 2000. It concentrates on radioecological investigation and monitoring of rivers and their inflows in Kazakhstan, Uzbekistan, Tajikistan, and Kyrgyzstan. Methodology and preliminary results of the project were reported and published in the proceedings of the 7th International Nuclear Analytical Methods in the Life Sciences Conference¹ and other publications.^{2,3} This article presents a summary of the results of element and radionuclide composition along the Syrdarya river and its inflows in Kazakhstan during four expeditions.

Experimental

Field investigations

The first step in field investigations was to determine control points (CP) from which water, bottom sediments, soil, and vegetation samples were to be taken. The 15 CPs, labeled KZ-1 through KZ-15, are shown in Fig. 1.

For each water sampling point, the main physical and chemical parameters of the water were determined using Hydrolab[®] portable probes. Quantities measured with the probes included temperature, specific conductivity, total amount of dissolved substances (ions, colloidal particles, and organic matter), mineralization, pH, oxidation–reduction potential, and dissolved oxygen content. Before and after the measurements of physical and chemical parameters of water the probes were calibrated using standard specimens.

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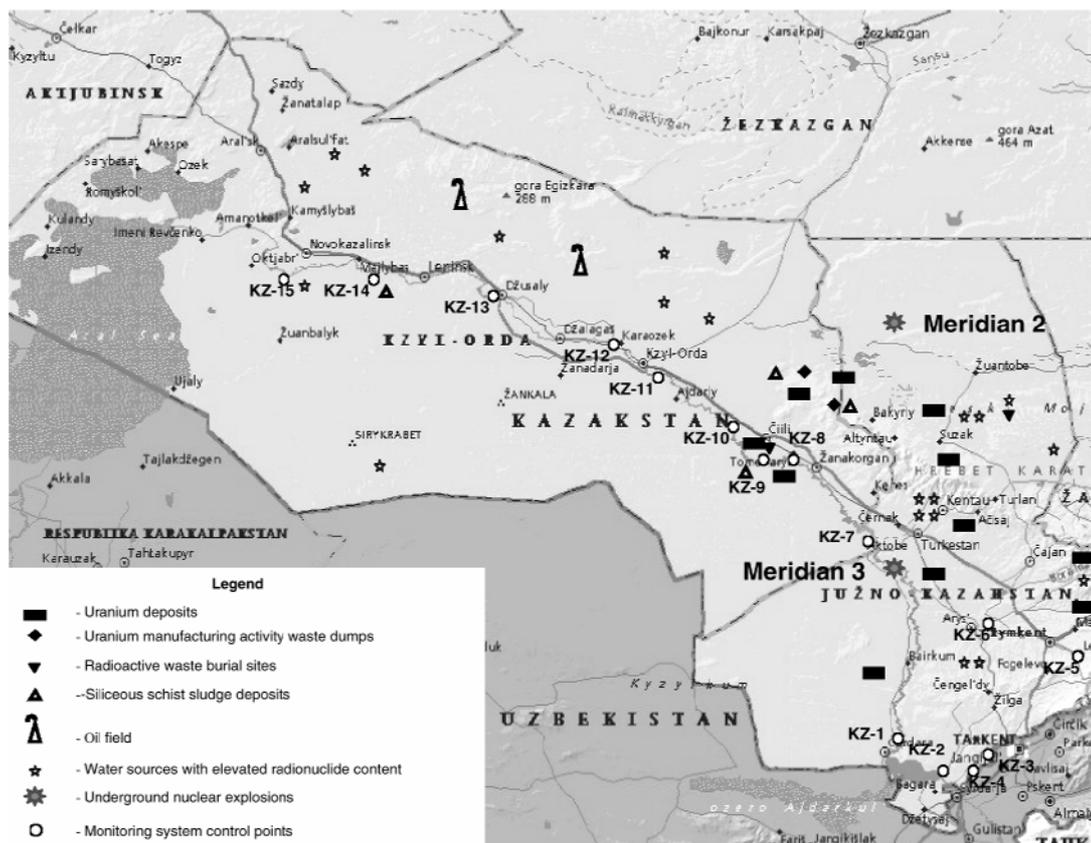


Fig. 1. Map of South Kazakhstan showing location of mineral resources, contaminated water sources, nuclear test sites, and control points

Water samples were taken from bridges or special floating structures so that no fewer than 5 samples could be taken across the width of the river section. Samples were taken from areas with active inflow that were free of algae and floating debris. The water sample container was lowered to a depth of 50 cm below the surface. The total water volume in one sample comprised 15 liter. The water was passed through paper filters, preserved by adding 3 ml of conc. HNO₃ per liter, and packed into polyethylene bottles. After drying, the filters were packed into polyethylene packages.

Soil samples were collected near the bank of the river at the CPs, at a point not subjected to floods and human activity. First, a square area 50 m on a side was delimited. Then five sample areas were marked within the site boundaries and their locations recorded. Each sample consists of a volume of soil 10×10 cm² in surface area and 5 cm deep. The samples combined from 5 points were placed into polyethylene packages and marked. The geographic coordinates of the sampling area were determined using a Garmin eMap[®] Global Positioning System (GPS) location system.

Riverside water plant (cane and algae) samples consisted of not less than 1 kg of plant material each.

The selected plant material was lightly dried, reduced to 3–5 cm fragments and packed into polyethylene packages.

Bottom sediment samples (not less than 2 kg each) were taken several meters from river's side line using a special sampler. After drying the selected samples were placed into polyethylene packages that were, in turn, placed into special impermeable containers.

At each CP, γ -background readings (total equivalent dose rate) were taken using a standard radiometer.

Laboratory investigations

The instrumental γ -spectrometric method was used for determination of radionuclide composition. Neutron activation analysis (NAA) and X-ray fluorescence (XRF) analysis were employed for determination of element and microelement composition.

Radionuclide analysis

Soil and bottom sediment samples of 1 kg each were first dried and homogenized by grinding in a ball mill to 150–200 μ m grain size. From the prepared material,

200 g samples were placed into a special beaker 70 mm in diameter with a bottom made of 100 μm polyethylene film.

Water samples were evaporated until dry and packed into fluoroplastic cuvettes of ~ 25 ml with the bottom thickness of 100 μm . Vegetation samples and water filters were ashed at 500 $^{\circ}\text{C}$ and placed, depending on their volume, either into beakers or cuvettes.

Radionuclide measurements were performed with three γ -spectrometers with different semiconductor detectors: Ortec GEM-2018 coaxial, Canberra GX-1520 wide-range, and Canberra BE-2020 planar. All the samples were arranged directly on the detector entry window. Measurement time varied up to three hours, depending on the sample activity.

Spectra were processed using INP-designed gamma-spectrometric analysis software that has been successfully applied for several years.

The γ -spectrometric method enables the determination or, at least the estimation, of radionuclide concentrations of the three natural radioactive series (uranium, thorium, and actinium) as well as the natural radionuclide ^{40}K and artificial radionuclide ^{137}Cs , which is indicative of global fallout. The list of radionuclides measured includes those with γ -radiation yield exceeding 1–5%. Accuracy of determination of radionuclides of natural series in soil and bottom sediments depends on the isotope. In order of accuracy, highest first, the radionuclides examined in this study were as follows: ^{214}Pb , ^{214}Bi , $^{212}\text{Pb} \rightarrow ^{234}\text{Th}$, ^{228}Ac , $^{208}\text{Tl} \rightarrow ^{226}\text{Ra}$, ^{224}Ra , $^{210}\text{Pb} \rightarrow ^{235}\text{U}$, $^{227}\text{Th} \rightarrow ^{223}\text{Ra}$, ^{219}Rn , ^{211}Pb .

Due to low concentrations of radionuclides in water, only ^{234}Th can be measured reliably. Therefore, radiochemical concentration of uranium and radium isotopes was employed for these samples.

Activation analysis

Analysis of bottom sediments, soils, vegetation ash, and dried water residuals was performed by the NAA method. Preliminary preparation of samples involved drying and powdering of the dried samples in a porcelain mortar. Analytic weights of 0.2 g were taken from the prepared samples by quartering. Selected samples were packed into doubled polyethylene bags and an aluminum container and were irradiated in the WWR-K nuclear reactor. Nichrome comparators were placed in the same container for determination of fluence and neutron spectrum. The neutron flux was $10^{12} \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$. Samples were irradiated for several hours, removed from the neutron beam, and cooled for four days. After cooling, they were repackaged and handed over for measurements.

The measurements were performed with the same semiconductor γ -spectrometers employed for radionuclide measurements. During the first session, Na, K, Ca, As, Br, Cd, Sb, La, Sm, Au, and U concentrations were measured. In the second measurement session, 30 to 32 days later, concentrations of Sc, Cr, Co, Fe, Zn, Se, Rb, Ag, Cs, Ba, Eu, Tb, Yb, Hf, Ta, Hg, and Th were determined. The nichrome comparators and standard samples (SGD-1a, S1-1, TM-2a, GXR-1, and GXR-5), which were irradiated in the same containers as the samples, were measured in the same measurement sessions. Calculation of the element concentrations was based on the measured activities of analytical isotopes, nuclear-physical parameters such as activation section, half-life, quantum yield of γ -radiation, and flux and spectrum of neutrons obtained from measurements of the comparators.

Measurement error is within 15% for the majority of the elements. For Ag, Cd, and Hg, however, the error in many cases exceeds 50%.

X-ray fluorescence analysis

Samples for XRF analysis were prepared by drying and homogenization by means of grinding in a ball mill. The samples were placed in 10 ml cuvettes with 100 μm thick polyethylene bottoms. The X-ray excitation source was a 3 mCi ^{109}Cd source. Measurements of characteristic spectra was performed with an X-ray spectrometer with a Si(Li) detector of 80 mm^2 active surface and resolution of 180 eV at 5.9 keV. The entry window of the detector is 25 μm -thick beryllium. Cuvettes with samples were placed on a special holder with the excitation source. The holder design protects the detector from direct radiation from the source. Characteristic XRF radiation from the samples was measured for 30 minutes. The obtained spectra were processed with a special computer code designed at INP NNC RK. In order to take into account the matrix effect, we use backscattered radiation from the excitation source. Special corrections were applied to account for selective absorption of characteristic radiation by the elements present in concentrations of 10% or more. This procedure measures 15 elements simultaneously with a detection threshold of 100 $\mu\text{g}/\text{g}$.

Most of the elements are determined according to the lines of the K-series, except Pb which is determined by the L-line. Validity of the analysis has been verified many times in recent years using IAEA reference materials.

Cation and anion water composition were determined using the standard potentiometer method.⁴

Results and discussion

The results of chemical and element composition measurements selected during the last two expeditions

verified the data obtained earlier.^{1,2} Therefore, this paper reports only the main results and general characterization of measured contamination.

Data on cation and anion water composition in the Syrdarya show high mineralization. In particular, SO_4^{2-} concentration exceeds the maximum allowable concentration by 2–3 times. The highest water mineralization corresponds to CPs KZ-3 and 4 (Saryagash health resort). Water electrical conductivity (200–3000 $\mu\text{S}/\text{sm}$) demonstrates its high mineral content. The other important physical and chemical water properties vary within the following limits: pH 6–9; oxidation-reduction potential 300–400 mV; dissolved oxygen content 0.8–12 mg/l.

Concentration of dissolved oxygen is an indicator of the rate of water contamination with organic fertilizers. The revealed values show a high concentration of organic pollutants in the studied water samples.

Macrocomposition of the bottom sediment and soil samples taken during all four expeditions was determined by XRF analysis. Concentrations of Ca, Ti, Mn, Fe, Rb, Sr, Y, Zr, Nb, Mo, and Ba were measured. In some samples Pb was also measured. Measurements showed that bottom sediments and soils differ slightly by their composition.

Contents of most of the elements in the investigated samples are within the limits for average world concentrations for sediments.⁵ An exception was high concentrations of Ca (6–11%) in all the samples, which exceed the world's average value of 2.5%.

Soil samples vary slightly in their composition. Some features of interest include the followings: Maximum concentrations of Fe (3.5%), Zn (100 $\mu\text{g}/\text{g}$), Rb (100 $\mu\text{g}/\text{g}$), Sr (350 $\mu\text{g}/\text{g}$), and Nb (14 $\mu\text{g}/\text{g}$) correspond to KZ-1 (eastern part of Shardarya reservoir). The bottom sediments from KZ-3 and 4 (vicinity of Saryagash) are characterized by increased concentration of Rb (80 $\mu\text{g}/\text{g}$), Sr (300 $\mu\text{g}/\text{g}$), Nb (12 $\mu\text{g}/\text{g}$), and Ba (750 $\mu\text{g}/\text{g}$). KZ-5 and 6 (in the suburbs of Shymkent) showed elevated levels of Ca (11 $\mu\text{g}/\text{g}$), Ti (0.5%), and Fe (2.5%). No significant seasonal changes in average concentrations of the elements in bottom sediments were noted.

The results of investigation by the NAA method of soil and bottom sediments show that the concentrations of the majority of the elements are within the world average limits. Selenium represents a considerable exception, since its concentration regularly exceeds the world-average value by 3–5 times.

The soils concentrations are similar to those in the bottom sediments, but about 10–20% higher. The highest concentrations of measured elements in soil are associated with big cities as follows:

Saryagash (KZ-3 and 4) – As (9 $\mu\text{g}/\text{g}$), Se (3 $\mu\text{g}/\text{g}$), Th (15 $\mu\text{g}/\text{g}$), U (2.5 $\mu\text{g}/\text{g}$);

Shymkent (KZ-5 and 6) – Cr (120 $\mu\text{g}/\text{g}$), Zn (130 $\mu\text{g}/\text{g}$), As (12 $\mu\text{g}/\text{g}$), Se (2.5 $\mu\text{g}/\text{g}$), Sb (3 $\mu\text{g}/\text{g}$);

Shyily (KZ-8, 9, and 10) – Se (2.5 $\mu\text{g}/\text{g}$), Th (14 $\mu\text{g}/\text{g}$), U (3 $\mu\text{g}/\text{g}$);

Kyzylorda (KZ-11 and 12) – Cr (160 $\mu\text{g}/\text{g}$), Zn (140 $\mu\text{g}/\text{g}$), Se (2.5 $\mu\text{g}/\text{g}$), Br (11 $\mu\text{g}/\text{g}$), Sb (10 $\mu\text{g}/\text{g}$).

A pronounced peculiarity of the bottom sediments is that the highest concentration of the most of the measured elements corresponds to KZ-1: Cr (300 $\mu\text{g}/\text{g}$), Co (17 $\mu\text{g}/\text{g}$), Zn (160 $\mu\text{g}/\text{g}$), Br (5 $\mu\text{g}/\text{g}$), Rb (150 $\mu\text{g}/\text{g}$), Sr (450 $\mu\text{g}/\text{g}$), Cs (10 $\mu\text{g}/\text{g}$), Th (16 $\mu\text{g}/\text{g}$), and U (3.6 $\mu\text{g}/\text{g}$). One can suppose that Shardarya reservoir is a kind of sink that concentrates considerable amounts of contamination carried by waters from Uzbekistan and the Keles River. Maximum contents of As and Sb are in bottom sediments at KZ-5, near Shymkent.

Data on microelement composition of water correlate well with the level of contamination of separate areas. KZ-1 and 2 at Shardarya reservoir are characterized by concentration values close to average, more evidence for its role as a contamination sink. At KZ-3 and 4 (Saryagash) the following maximal concentrations were observed: Cr (100 $\mu\text{g}/\text{l}$), Se (4 $\mu\text{g}/\text{l}$), Br (39 $\mu\text{g}/\text{l}$), Rb (6 $\mu\text{g}/\text{l}$), Cd (3 $\mu\text{g}/\text{l}$). At KZ-5 and 6 (Shymkent) there were observed maximal concentrations of As (2 $\mu\text{g}/\text{l}$), Sb (0.8 $\mu\text{g}/\text{l}$), and Ra (1.4 $\mu\text{g}/\text{l}$) along with high contents of Zn (20 $\mu\text{g}/\text{l}$), Se (3 $\mu\text{g}/\text{l}$), Br (20 $\mu\text{g}/\text{l}$). The highest concentrations of Th (0.1 $\mu\text{g}/\text{l}$), U (20 $\mu\text{g}/\text{l}$) and Ag (0.5 $\mu\text{g}/\text{l}$) in water were observed in the lower courses of Syrdarya River at KZ-13 and 14. This is most probably as a consequence of gradual accumulation.

We conclude that the main mechanisms for heavy metal contamination of Syrdarya waters in Kazakhstan are inflows from Uzbekistan and the Keles and Arys tributaries. Shardarya reservoir is a potential source for such contamination due to its considerable content of heavy metals in the bottom sediments.

Tables 1 and 2 show values of radionuclide concentrations, averaged on all results, in soil and bottom sediments in every CP. According to the data, the amount of the artificial radionuclide ^{137}Cs in these samples does not have major peculiarities. Average values of its concentration in soil and bottom sediments correspond to background values caused by global fallout. The exceptions are: (1) that ^{137}Cs contents in soil and bottom sediments in mountain areas (KZ-2 through 5) exceed those for flat country and (2) the ^{137}Cs concentration in bottom sediments in KZ-1 is higher than all the other CPs. This is true for all the other radionuclides at this CP, because of contaminant storage in the Shardarya reservoir. Concentrations of natural radionuclides at all studied CPs is, in general, considerably higher than in other areas of Kazakhstan.

Table 1. Soil radionuclide concentration at control points on the Syrdarya shore and its inflows in Kazakhstan (in Bq/kg)

Control point	$^{238}\text{U}^*$	^{234}Th	^{226}Ra	^{214}Pb	^{214}Bi	^{210}Pb	$^{232}\text{Th}^*$	^{228}Ac
KZ-01	35 ± 4	34 ± 3	52 ± 7	33 ± 2	30 ± 3	64 ± 7	49 ± 4	43 ± 4
KZ-02	34 ± 3	27 ± 3	52 ± 7	31 ± 2	29 ± 3	56 ± 7	43 ± 5	39 ± 4
KZ-03	42 ± 5	32 ± 3	58 ± 7	37 ± 3	35 ± 3	65 ± 7	50 ± 5	53 ± 5
KZ-04	33 ± 3	29 ± 3	56 ± 6	36 ± 2	33 ± 3	82 ± 8	43 ± 4	52 ± 5
KZ-05	29 ± 3	25 ± 3	55 ± 7	33 ± 2	31 ± 3	68 ± 7	33 ± 3	43 ± 4
KZ-06	30 ± 3	24 ± 3	54 ± 7	28 ± 2	27 ± 2	50 ± 6	32 ± 3	35 ± 4
KZ-07	30 ± 3	31 ± 3	56 ± 7	32 ± 2	31 ± 3	47 ± 6	42 ± 4	44 ± 4
KZ-08	37 ± 3	38 ± 4	70 ± 8	39 ± 3	36 ± 4	42 ± 6	46 ± 5	47 ± 4
KZ-09	42 ± 4	35 ± 4	65 ± 8	40 ± 3	37 ± 4	40 ± 6	48 ± 5	47 ± 5
KZ-10	40 ± 4	32 ± 3	54 ± 7	33 ± 2	30 ± 3	44 ± 6	43 ± 4	42 ± 4
KZ-11	32 ± 3	30 ± 3	55 ± 7	29 ± 2	27 ± 3	54 ± 6	38 ± 4	37 ± 4
KZ-12	34 ± 4	30 ± 3	56 ± 7	33 ± 2	32 ± 3	49 ± 6	41 ± 4	45 ± 4
KZ-13	32 ± 3	29 ± 3	53 ± 7	35 ± 2	32 ± 3	46 ± 6	33 ± 3	42 ± 4
KZ-14	36 ± 4	28 ± 3	46 ± 6	29 ± 2	26 ± 3	37 ± 5	42 ± 4	34 ± 4
KZ-15	30 ± 3	29 ± 3	43 ± 6	28 ± 2	26 ± 3	41 ± 6	32 ± 3	37 ± 4

Control point	^{224}Ra	^{212}Pb	^{212}Bi	^{208}Tl	^{235}U	^{40}K	^{137}Cs
KZ-01	40 ± 5	42 ± 2	43 ± 3	41 ± 4	2.7 ± 0.8	640 ± 40	5.7 ± 0.4
KZ-02	39 ± 5	38 ± 2	38 ± 3	36 ± 3	2.3 ± 0.6	580 ± 30	3.9 ± 0.7
KZ-03	50 ± 6	55 ± 3	54 ± 4	46 ± 4	2.2 ± 0.6	720 ± 50	4.5 ± 0.8
KZ-04	51 ± 6	52 ± 3	56 ± 4	45 ± 4	2.2 ± 0.6	700 ± 50	5.2 ± 0.5
KZ-05	42 ± 5	45 ± 3	50 ± 4	39 ± 4	2.3 ± 0.6	570 ± 40	5.0 ± 0.6
KZ-06	35 ± 5	30 ± 2	31 ± 3	31 ± 3	1.7 ± 0.7	490 ± 50	2.3 ± 0.7
KZ-07	43 ± 5	40 ± 2	36 ± 3	37 ± 4	2.0 ± 0.6	540 ± 30	1.7 ± 0.7
KZ-08	46 ± 5	45 ± 3	51 ± 4	41 ± 4	1.8 ± 0.6	600 ± 50	2.3 ± 0.6
KZ-09	47 ± 6	49 ± 3	51 ± 4	43 ± 4	2.0 ± 0.6	570 ± 40	3.1 ± 0.7
KZ-10	36 ± 5	43 ± 3	44 ± 3	36 ± 4	2.1 ± 0.7	620 ± 50	3.8 ± 0.5
KZ-11	33 ± 5	38 ± 2	38 ± 3	34 ± 3	2.4 ± 0.7	520 ± 40	6.3 ± 0.6
KZ-12	43 ± 5	42 ± 3	39 ± 3	39 ± 4	2.0 ± 0.7	620 ± 50	3.5 ± 0.7
KZ-13	30 ± 5	40 ± 3	47 ± 4	38 ± 4	2.1 ± 0.6	570 ± 50	2.9 ± 0.7
KZ-14	29 ± 5	33 ± 3	35 ± 3	31 ± 3	2.1 ± 0.7	570 ± 50	4.0 ± 0.6
KZ-15	31 ± 5	35 ± 2	37 ± 3	32 ± 3	1.8 ± 0.6	540 ± 40	2.3 ± 0.6

* According to NAA data.

Table 2. Radionuclide composition of bottom sediments at control points on the Syrdarya and its inflows in Kazakhstan (in Bq/kg)

Control point	$^{238}\text{U}^*$	^{234}Th	^{226}Ra	^{214}Pb	^{214}Bi	^{210}Pb	$^{232}\text{Th}^*$	^{228}Ac
KZ-01	49 ± 5	42 ± 4	62 ± 7	40 ± 3	40 ± 4	55 ± 7	56 ± 5	62 ± 6
KZ-02	37 ± 3	27 ± 3	44 ± 6	31 ± 2	29 ± 3	32 ± 5	36 ± 4	35 ± 4
KZ-03	38 ± 3	32 ± 3	40 ± 5	35 ± 2	34 ± 3	43 ± 6	47 ± 4	52 ± 5
KZ-04	43 ± 3	35 ± 3	50 ± 6	37 ± 3	37 ± 4	43 ± 6	47 ± 4	50 ± 5
KZ-05	30 ± 3	30 ± 3	48 ± 6	31 ± 2	29 ± 3	40 ± 6	34 ± 3	38 ± 4
KZ-06	33 ± 3	30 ± 3	34 ± 5	31 ± 2	28 ± 3	43 ± 6	35 ± 4	41 ± 4
KZ-07	34 ± 3	31 ± 3	44 ± 5	32 ± 2	32 ± 3	39 ± 6	36 ± 4	40 ± 4
KZ-08	33 ± 3	28 ± 3	42 ± 5	33 ± 2	32 ± 3	34 ± 5	33 ± 4	40 ± 4
KZ-09	34 ± 3	27 ± 3	53 ± 6	33 ± 2	32 ± 3	34 ± 5	37 ± 4	39 ± 4
KZ-10	39 ± 4	29 ± 3	47 ± 6	35 ± 2	34 ± 3	36 ± 6	40 ± 4	38 ± 4
KZ-11	44 ± 4	36 ± 4	52 ± 6	38 ± 3	37 ± 4	42 ± 6	49 ± 5	51 ± 5
KZ-12	31 ± 3	27 ± 3	44 ± 5	30 ± 2	38 ± 3	30 ± 5	34 ± 3	36 ± 4
KZ-13	38 ± 4	27 ± 3	46 ± 6	35 ± 2	30 ± 3	35 ± 6	40 ± 4	43 ± 4
KZ-14	33 ± 3	32 ± 3	54 ± 6	37 ± 3	36 ± 4	43 ± 6	43 ± 4	44 ± 4
KZ-15	34 ± 3	29 ± 3	50 ± 6	30 ± 2	29 ± 3	37 ± 6	36 ± 4	39 ± 4

Table 2. (Continued)

Control point	^{224}Ra	^{212}Pb	^{212}Bi	^{208}Tl	^{235}U	^{40}K	^{137}Cs
KZ-01	61 ± 6	60 ± 3	63 ± 4	52 ± 5	2.6 ± 0.7	660 ± 50	2.9 ± 0.7
KZ-02	32 ± 4	33 ± 2	38 ± 3	35 ± 4	2.0 ± 0.7	600 ± 40	<1.0
KZ-03	47 ± 4	47 ± 2	50 ± 4	45 ± 4	2.9 ± 0.6	770 ± 40	1.2 ± 0.8
KZ-04	47 ± 5	49 ± 2	52 ± 4	44 ± 4	1.8 ± 0.8	680 ± 50	1.2 ± 0.8
KZ-05	33 ± 4	35 ± 2	40 ± 4	32 ± 3	2.2 ± 0.8	500 ± 40	1.3 ± 1.0
KZ-06	37 ± 4	37 ± 2	44 ± 4	30 ± 3	2.3 ± 0.7	580 ± 40	1.4 ± 0.9
KZ-07	38 ± 5	38 ± 2	40 ± 4	36 ± 4	2.1 ± 0.6	580 ± 30	<1.0
KZ-08	43 ± 5	37 ± 2	36 ± 3	34 ± 4	1.7 ± 0.7	590 ± 40	<1.0
KZ-09	40 ± 4	37 ± 2	45 ± 4	36 ± 4	2.1 ± 0.6	660 ± 40	<1.0
KZ-10	40 ± 4	39 ± 2	42 ± 3	39 ± 4	1.8 ± 0.6	630 ± 50	<1.0
KZ-11	52 ± 5	52 ± 3	51 ± 4	52 ± 4	2.7 ± 0.5	580 ± 40	<1.0
KZ-12	36 ± 4	34 ± 2	36 ± 3	31 ± 4	1.7 ± 0.6	650 ± 50	<1.0
KZ-13	42 ± 4	41 ± 2	42 ± 3	38 ± 4	2.0 ± 0.8	590 ± 40	<1.0
KZ-14	44 ± 4	44 ± 2	48 ± 4	43 ± 4	2.1 ± 0.7	630 ± 50	<1.0
KZ-15	43 ± 4	37 ± 2	42 ± 4	36 ± 3	2.0 ± 0.7	620 ± 50	<1.0

* According to NAA data.

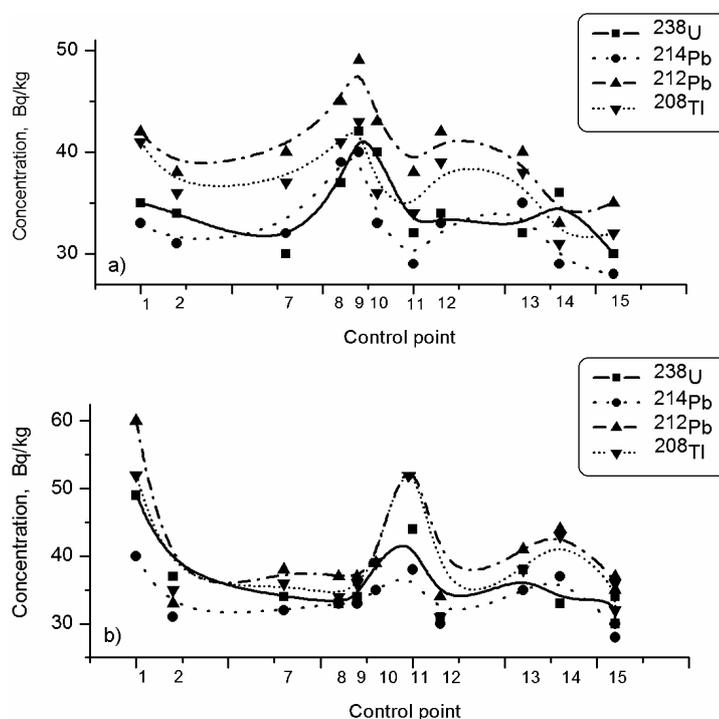


Fig. 2. Radionuclide distribution in soil (a) and bottom sediments (b) along the Syrdarya riverbed

This is almost certainly due to the presence of uranium deposits. The highest concentrations of ^{238}U and ^{232}Th series in soil of the Syrdarya river basin correspond to KZ-3 and KZ-4 (Keles River). High concentrations of radionuclides in soils and bottom sediments of the river are also typical for these CPs.

Figure 2 shows the distribution of concentrations of ^{238}U , ^{214}Pb , ^{212}Pb , and ^{208}Tl radionuclides in soil and bottom sediments along the Syrdarya river bed. The highest concentration of these radionuclides in soil

corresponds to KZ-8, KZ-9, and KZ-10, near the uranium deposits in Shyily. The highest concentrations of these radionuclides in bottom sediments, as noted above, correspond to KZ-1. The second maximum at KZ-11 shows the influence of the uranium deposit at Shyily.

The distribution of radionuclide concentrations by soil depth at separate CPs has been studied. The results, averaged over all data, are presented in Table 3. This distribution, to a depth of 40 cm, has a similar character

for the majority of the radionuclides. Exceptions are ^{137}Cs and ^{210}Pb , whose concentration near the surface is considerably higher than in lower layers. Cesium contamination is connected with its fallout from the atmosphere, which concentrates detectable cesium in the

upper layer of soil. The presence of this radionuclide in lower layers of soil is a consequence of its migration from the surface. The increased ^{210}Pb content of the upper layers is because it is deposited from the air as a result of ^{222}Rn decay.

Table 3. Radionuclide concentration in soil layers in Syrdarya river basin (in Bq/kg)

Soil layer, cm	^{234}Th	^{226}Ra	^{214}Pb	^{214}Bi	^{210}Pb	^{228}Ac
0–5	30.7 ± 3.9	58.8 ± 7.2	29.3 ± 1.6	28.1 ± 2.1	57.6 ± 7.7	50.8 ± 3.8
5–10	26.9 ± 4.1	62.5 ± 7.0	30.4 ± 1.4	28.4 ± 2.4	36.8 ± 7.2	52.6 ± 4.0
10–15	29.1 ± 3.7	56.2 ± 6.8	31.2 ± 1.7	28.4 ± 2.3	37.6 ± 6.9	51.9 ± 4.1
15–20	26.6 ± 3.8	63.2 ± 7.7	31.1 ± 1.5	29.6 ± 2.4	34.9 ± 7.0	50.3 ± 3.9
20–30	25.4 ± 3.7	57.1 ± 7.3	30.2 ± 1.4	27.6 ± 2.5	34.0 ± 6.8	51.7 ± 4.2
30–40	23.7 ± 3.9	58.8 ± 7.1	30.0 ± 1.6	28.5 ± 2.2	31.0 ± 6.7	50.5 ± 4.1
Average:	26.9 ± 3.8	59.4 ± 7.2	30.4 ± 1.5	28.4 ± 2.3	38.7 ± 7.0	51.3 ± 4.0

Soil layer, cm	^{224}Ra	^{212}Pb	^{212}Bi	^{208}Tl	^{40}K	^{137}Cs
0–5	40.2 ± 4.7	40.0 ± 1.8	53.7 ± 4.3	36.2 ± 3.2	620 ± 40	6.0 ± 1.0
5–10	44.8 ± 4.4	41.3 ± 1.6	50.2 ± 4.0	38.2 ± 3.4	620 ± 40	2.5 ± 0.8
10–15	48.3 ± 4.5	41.7 ± 1.9	53.5 ± 4.0	37.7 ± 3.0	640 ± 40	2.5 ± 0.8
15–20	49.8 ± 4.4	41.2 ± 1.9	50.5 ± 4.2	38.1 ± 3.1	615 ± 40	3.0 ± 0.8
20–30	48.4 ± 4.7	40.4 ± 2.0	51.3 ± 3.9	37.1 ± 2.8	620 ± 30	2.4 ± 0.6
30–40	45.6 ± 4.3	40.5 ± 1.7	48.8 ± 4.0	37.5 ± 3.3	615 ± 40	1.3 ± 0.4
Average	46.2 ± 4.5	40.9 ± 1.8	51.3 ± 4.1	37.5 ± 3.1	620 ± 40	3.0 ± 0.7

Table 4. Concentration of ^{238}U and ^{234}Th (in $\mu\text{Bq/l}$) in water of Syrdarya river and its inflows

Control point	^{238}U			^{234}Th		
	Spring	Autumn	Average	Spring	Autumn	Average
KZ 01	200 ± 30	210 ± 30	205 ± 30	150 ± 30	100 ± 20	125 ± 30
KZ 02	170 ± 30	230 ± 30	200 ± 30	120 ± 20	150 ± 30	135 ± 30
KZ 03	150 ± 30	240 ± 30	195 ± 30	140 ± 20	120 ± 20	130 ± 20
KZ 04	90 ± 20	220 ± 30	155 ± 30	110 ± 20	160 ± 30	135 ± 30
KZ 05	90 ± 20	140 ± 20	115 ± 30	80 ± 10	110 ± 20	95 ± 20
KZ 06	100 ± 20	110 ± 20	105 ± 20	60 ± 10	80 ± 10	70 ± 10
KZ 07	130 ± 30	200 ± 30	165 ± 30	100 ± 20	110 ± 20	105 ± 20
KZ 08	160 ± 30	220 ± 30	190 ± 30	130 ± 20	160 ± 30	145 ± 30
KZ 09	190 ± 30	270 ± 30	230 ± 30	190 ± 30	200 ± 30	195 ± 30
KZ 10	170 ± 30	250 ± 30	210 ± 30	140 ± 20	190 ± 30	215 ± 30
KZ 11	150 ± 30	230 ± 30	190 ± 30	130 ± 20	170 ± 30	150 ± 30
KZ 12	170 ± 30	240 ± 30	205 ± 30	150 ± 30	190 ± 30	170 ± 30
KZ 13	180 ± 30	260 ± 30	220 ± 30	180 ± 30	190 ± 30	185 ± 30
KZ 14	160 ± 20	240 ± 30	200 ± 30	140 ± 20	180 ± 30	160 ± 30
KZ 15	150 ± 20	250 ± 30	200 ± 30	150 ± 30	190 ± 30	170 ± 30

Table 5. Concentration of ^{234}Th in points of interest along the Syrdarya

Site	Soil, Bq/kg	Sediment, Bq/kg	Water, mBq/l	Vegetation, mBq/kg
Upper Syrdarya; CP-1	34 ± 3	42 ± 4	125 ± 30	5.3 ± 2.2
Keles river; CP 3, 4	32 ± 3	34 ± 3	135 ± 30	7.7 ± 2.0
Arys river; CP 5, 6	25 ± 3	30 ± 3	80 ± 20	5.1 ± 1.7
Shyily; CP 8, 10	35 ± 3	28 ± 3	185 ± 30	3.6 ± 1.5
Kyzylorda; CP 11	30 ± 3	36 ± 4	150 ± 30	23 ± 2.0
Lower Syrdarya; CP 11-15	29 ± 3	29 ± 3	170 ± 30	8.4 ± 1.7

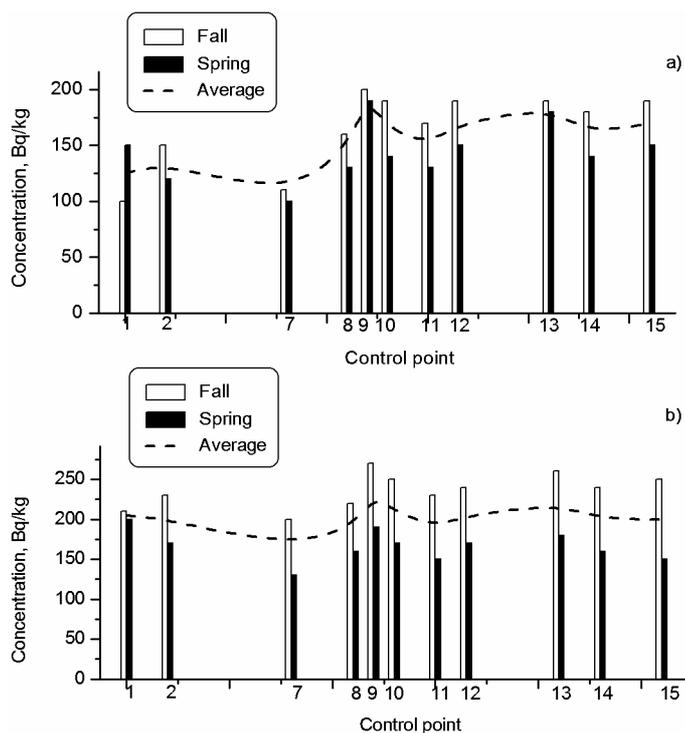


Fig. 3. Distribution of ^{234}Th (a) and ^{238}U (b) in water along the Syrdarya riverbed

Concentrations of ^{234}Th and ^{238}U , in water samples selected from all CPs during all four expeditions were determined using the methods of γ -spectrometry and NAA. Table 4 summarizes the results. Concentration of ^{238}U in water in autumn is considerably higher (by about 2.5 times) than in spring. For ^{234}Th , the difference is less apparent. Such seasonal variation is probably related to geochemical peculiarities of these radionuclides.

Figure 3 shows distribution of ^{234}Th and ^{238}U concentrations in water along the Syrdarya riverbed. Concentration of these radionuclides increases considerably at KZ-8, KZ-9, and KZ-10, near the uranium deposits at Shyily, and stays at this level all the way to the Aral Sea. The general environmental radiation situation in the region is shown in the data on the content of ^{234}Th in different environmental objects at separate areas of Syrdarya river basin (Table 5). The highest concentration of this radionuclide in soil corresponds to the upper Syrdarya (KZ-1) and the uranium deposits at Shyily (KZ-8 through KZ-10). Soil sampling at KZ-1 was done in the Syrdarya flood plane, which is covered during high-water periods. Thus, the increased concentrations of ^{234}Th in these soils can be explained by transfer of this radionuclide by water from Uzbekistan. Such a mechanism is also indicated by the maximum in concentration of ^{234}Th in bottom sediments at KZ-1 (42 Bq/kg). The second maximum for bottom sediments at KZ-11 is evidence of the influence of uranium deposits at Shyily. The concentrations of this

radionuclide in water at KZ-8, KZ-9, and KZ-10 and in vegetation at KZ-11 are also evidence of this.

Conclusions

The Navruz Project involved large-scale investigations of the rate and character of contamination of the Syrdarya river basin in Kazakhstan. The results allowed characterizing the general radiation and ecological situation in this region. In the study area, the highest contamination of natural radionuclides was observed in the eastern part of the Syrdarya reservoir, the Keles river bed, and the vicinity of uranium deposits at Shyily. High concentrations of heavy metals and toxic elements were measured in the bottom of the Syrdarya reservoir and surrounding the large cities of Shimkent and Saryagash. The project results indicate the negative influence of these pollutants on radionuclide and element composition of water in the Syrdarya. It was also noted that high selenium concentrations in all environmental objects is typical for all investigated areas. Selenium concentration in the water of the Syrdarya and its inflows exceeds the standard for maximum permissible concentration in drinking water by 2–4 times.

During the course of the Project, the need for additional investigations became apparent. Therefore, a program of further work, the International Navruz-2 Project, has been developed.

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