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Results of radiological survey of the territory adjacent to the "Atomic" lake

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The article presents working results of radiation status survey in the territory adjacent to the "Atomic lake", a venue of the first USSR excavation explosion. In the course of research, a picture of areal radiation contamination has been obtained in the territory with technogenic radionuclides ^{137}Cs , ^{241}Am , ^{152}Eu . A pattern of radionuclide distribution in depth is shown at different spots (crater bank, Shagan river floodplain, the area of the external reservoir). Data is presented on concentrations of technogenic radionuclides ^{3}H, $^{239+240,238}$Pu , ^{90}Sr , ^{60}Co , ^{154}Eu , ^{152}Eu in soil.

Keywords: Excavation nuclear explosion, "Atomic lake", Shagan river, technogenic radionuclides.

Introduction

The purpose of experimental industrial underground nuclear explosion at the Semipalatinsk Test Site was to obtain information about the possibility of conducting such explosions to form deep craters, thus showing the usefulness, and, perhaps the need of using nuclear charges to create reservoirs in arid regions of the country. This explosion was conducted on 15.01.1965 at the confluence of the rivers Shagan and Aschisu within the Balapan site. Preparation works and the explosion itself were performed within the frame of special projects, containing the complex of measures on radiation and seismic safety of population [1]. After all construction works, two large reservoirs were formed: internal – in crater and external – due to flooding of the flood plains of the Shagan and Aschisu rivers (Figure 1).

It should be noted that specialists of many scientific institutes, in the implementation of various types of scientific integrated radiation research programs paid great attention to the assessment of radiation situation on the artificially created place and to its surrounding territory. The study of the radioecological state of this object and area around it was continued in the 1990s, as part of the implementation of international monitoring programs. A great contribution to the study and assessment of the radioecological state was made by specialists of the National Nuclear Center of the RK engaged in researching the territory of the test site after its closure. The results of works showed that, at present, only at the dump of soil of the Shagan river and at small distances from it, the levels of natural gamma background and the content of artificial radionuclides in the soil exceed the levels of similar indicators from global deposition (Figure 2). The maximum total area of such sections does not exceed 20 km^2 [2]. Nevertheless, the

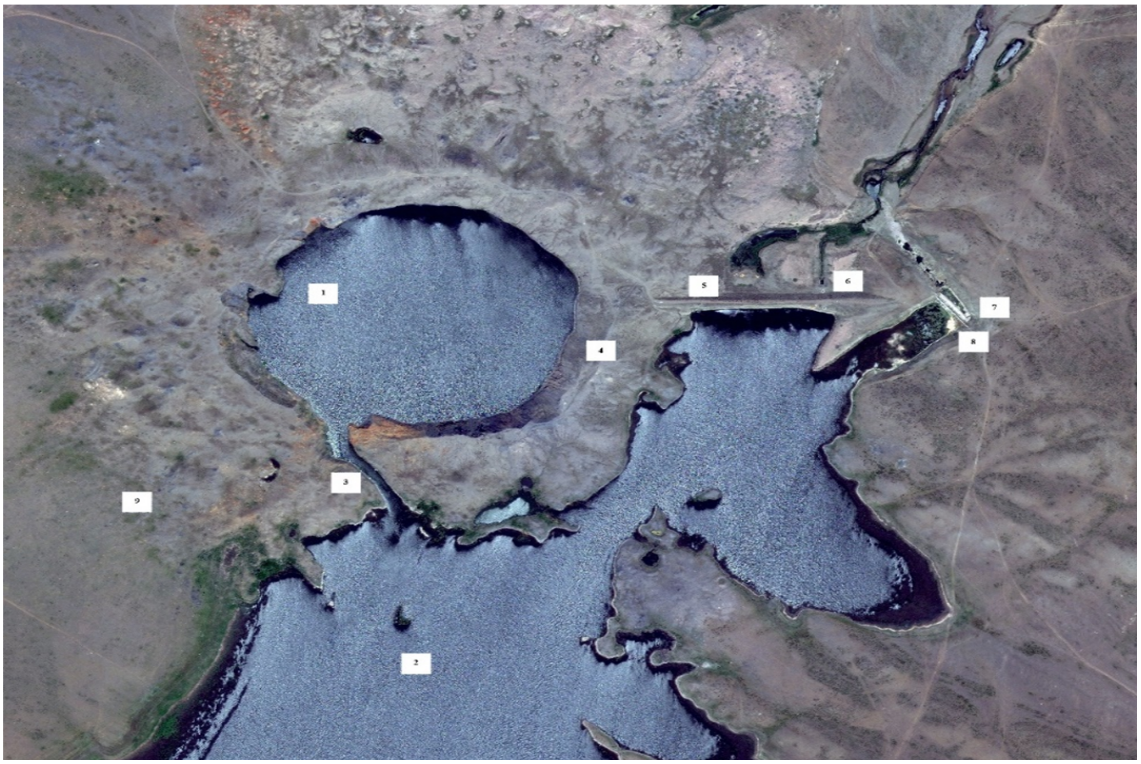

Figure 1. Scheme of artificial water reservoir on Shagan river and assembly of its structure. 1 – Internal reservoir; 2 – External reservoir; 3 – Water supply canal; 4 – Dump of ground; 5 – Rock-fill dam; 6 – Bottom drain; 7 – Flow side spillway with side weir; 8 – The remains of destroyed dam; 9 – Border of dump of soil [1].

analysis of the currently available data showed that they reflect only the general character of the radioactive contamination of the territory. The obtained results do not allow getting information that could characterize mechanisms and determine the exact boundaries of radioactive contamination, highlight any features in radionuclides distribution, and make assumptions about the contribution to the contamination of territory of one or another source.

Thus, the purpose of this work was to determine the character of radioactive contamination at the area of the "Atomic" lake.

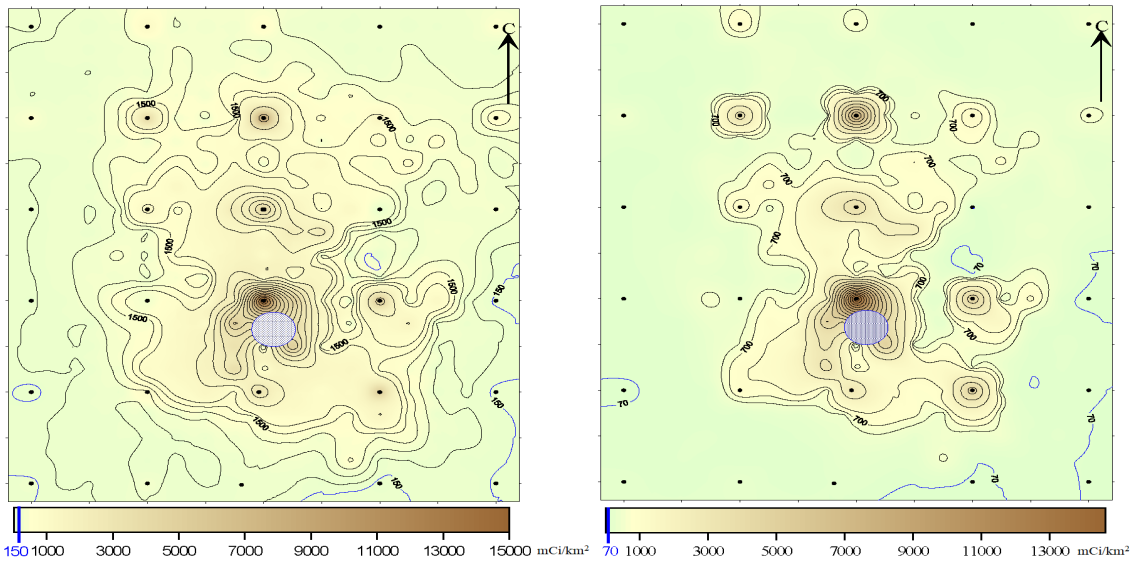

Figure 2. Distribution of radionuclides ^{137}Cs and ^{90}Sr at the area of the "Atomic" lake.

Work methodology

To assess the current radiation situation in the area of the "Atomic" lake, the method of pedestrian gamma-spectrometric survey was used as the main one. This survey allows obtaining information about surface radioactive contamination of the area by three main "products" of nuclear explosion – by products of nuclear charge fission (^{137}Cs), by products of structural materials activation and environmental elements (^{152}Eu), and by nuclear charge material itself (^{241}Am). In addition, this method allows assessing radioactive contamination of the area without environmental samplings and accordingly, without any laboratory analysis of the samples. The boundaries of the survey area were chosen taking into account the available information about the radioactive fallout plume, which stretched northeast from the crater (of "Atomic" lake). Thus, the areal gamma-spectrometric survey was carried out in both zones, at the crater bank and along the plume; therefore, most of the survey area was located north of the "Atomic" lake (Figure 3). It was assumed, that results of gamma-spectrometric survey would help to obtain the picture of radiation situation, to determine the boundaries and to identify possible features of radioactive contamination.

Pedestrian gamma-survey. Field gamma-spectrometric systems based on scintillation detectors with lanthanum bromide ($LaBr_3(Ce)$) crystals and ORTEC DigiBase pulse analyzers were used in course of work. The whole territory was divided into elementary sectors with size (240×240) m, and survey network of (20×20) m (with coordinates of all network points) was applied for each sector. The accepted distance between survey points practically guarantees detection of radioactive fallout plumes, as well as relatively small (20×20) areas of radioactive contamination, which is consistent with the purpose of this type survey.

The division of the territory into survey sectors allowed simultaneous application of several field gamma-spectrometers in different survey sectors and in case of errors during field measurements, conducting repeated measurements in each specific sector. In other words, this approach made it possible to systematize the process of gamma-spectrometric surveying of large areas.

In general, the process of pedestrian gamma-spectrometric survey consisted of the following stages. The survey sector was selected, where the "operator" making the survey, moved along the given route – according to coordinates of the survey sector points, i.e. along the profiles, with a distance 20 m between them; with a continuous speed of movement – (1-2) km/h. The operator was moving along the profiles using a satellite navigation device.

The detector was fixed on the body of the "operator" at the height of 0,5 m from the ground surface. The height was set by means of adjusting belts and measuring tape (tapeline), during the motion of the "operator" with the height of the detector remained unchanged.

While the "operator" moved along the profiles, a continuous accumulation of gamma-spectrum was performed and they (recordings) were saved on a mobile computer (laptop). The time for one gamma-spectrum accumulations 10 s, then, in the automatic mode, the current spectrum was saved and then the next spectrum was started, etc. On average, 1800 spectra were accumulated and recorded in each sector.

The next stage of the work was the processing of gamma spectra and preparation of data for constructing maps of surface radioactive contamination of the

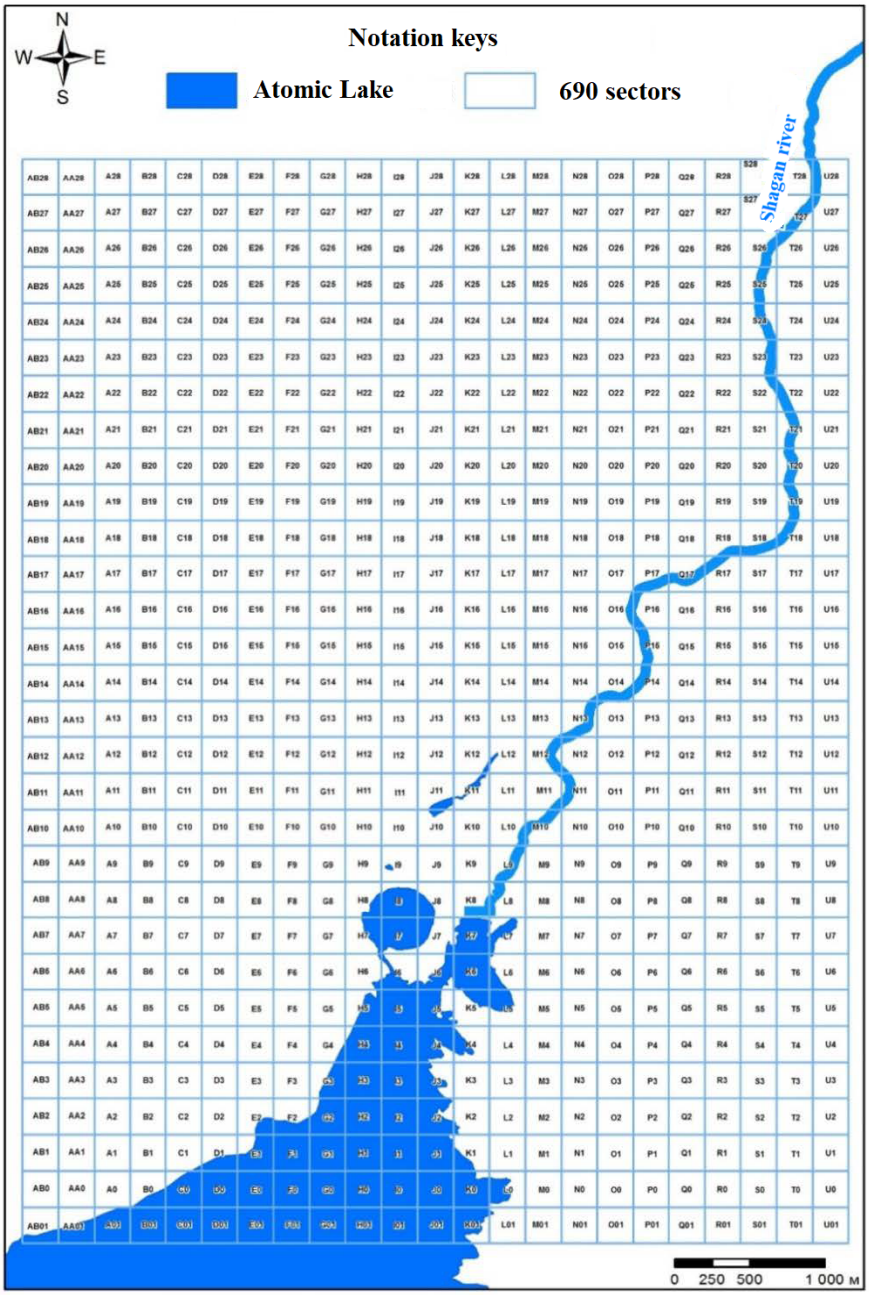

Figure 3. Boundaries of pedestrian gamma-spectrometric survey of the "Atomic" lake.

territory. To process the available spectra (total of approximately 600 000 gamma spectra were obtained during the survey), the "Spectrool" gamma-spectrum processing program allowing for all data to be processed in the shortest time (5-6 working days) was used. The sensitivity of the pedestrian gamma-spectrometric survey method was as follows:

- ^{137} Cs – 100 Bq/kg;
- ^{241} Am – 200 Bq/kg;
- ^{152} Eu – 300 Bq/kg.

Sampling. In addition to gamma-spectrometric survey, soil samples were taken to characterize the radioactive contamination (radionuclide composition, distribution in vertical profile). Sampling points were selected based on the fol-

lowing considerations:

- in places of maximum radioactive contamination on the crater bank, layer-wise soil samples were collected at the depth of 6 m with 1 m interval (borehole 1, 2, 3);
- in the flood plain of Shagan river at the territory with non typical character of radionuclides activity distribution (p. 1, 2, 3, 4, 5) and in the coastal zone of the external reservoir (p. 1-15);
- from the crater of "Atomic" lake along the way to north-west direction (p. A1-A12).

Figure 4 shows the scheme of soil sampling.

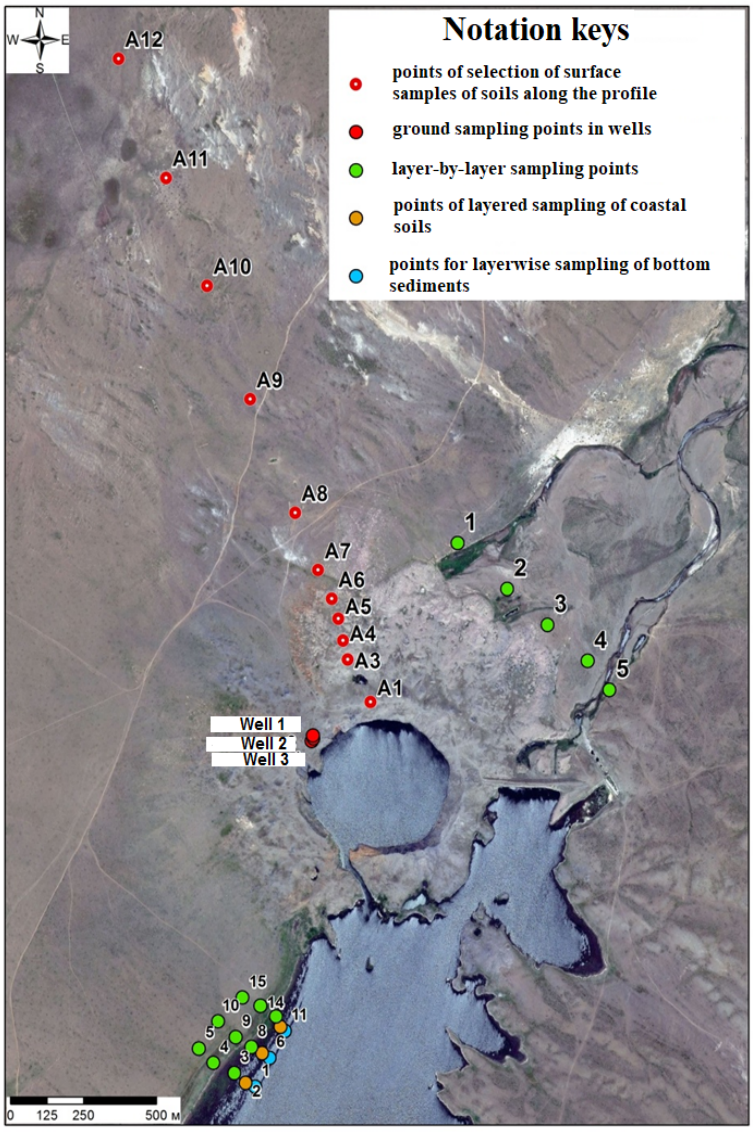

Figure 4. Soil samplings points.

Samples from boreholes. To determine the character of artificial radionuclides vertical distribution at the "Atomic" lake bank, on one of the flat area located within 25 m, 3 boreholes were drilled. Depth of drilled boreholes was 6 m. Samplings were taken in interval of 1 m.

Subsurface soil sampling. To determine the character of radionuclides distribution in depth of different areas, differing in soil type, soil samples were collected

at the depth up to 50 cm. The first area was found in flood plain part of the Shagan river, located between two courses of the Shagan river. Samples of bottom sediments and coastal (flooded) and coastal soils were collected in the zone of the external reservoir.

Surface soil sampling. To characterize radioactive contamination and to calibrate field gamma spectrometers, surface soil samples were collected. For this, surface soil samples were collected along the line from the crater of "Atomic" lake and further in the north-west direction.

Construction maps of surface distribution of radionuclides.

To perform spatial analysis of existing data using geoinformation systems, two software products were used: "Golden Software Surfer»"and "ArcGis".

Laboratory research.

To determine concentrations of $^{239+240}$Pu,^{238}Pu alpha-spectrometers by "Canberra" were used. An alpha-spectrometer consists of a vacuum chamber, $\alpha-$radiation detector, and it pulse analyzer and "GENIE2000" software. Limits of detection were calculated based on the type of sample and time of measurement. To determine the specific activity of ^{3}H, ^{90}Sr, and other $\beta-$emitting radionuclides, "TRI-CARB 2900TR" beta-spectrometer by "Hewlett Packard" and "Progress" scintillation beta-spectrometer with software were used. Limits of detection were calculated based on the type of sample and time of measurement. The content of $\gamma-$emitting radionuclides in the soil was determined using gamma-spectrometers by "Canberra" and "Ortec". The spectrometer consists of $\gamma-$radiation detector on the basis of a crystal of hyper pure germanium, pulse analyzer and software package. Limits of detection were calculated based on geometry of product and time of measurement. For the energy calibration of spectrometers, a set of standard $\gamma-$sources (sample spectrometric gamma-sources) and to calibrate geometry, voluminous activity measures of special purpose containing ^{137}Cs, ^{152}Eu, ^{241}Am radionuclides were used. All measurements and analyzes of soil samples were carried out in accordance with existing state standards, normative and methodological documents of the Republic of Kazakhstan [3, 4, 5, 6, 7].

Work results

Upon the results of pedestrian survey, a picture was obtained, characterizing radioactive contamination of the territory adjacent to the "Atomic" lake. In general, the obtained data allowed to detail the picture of radioactive contamination and confirmed the results of previous studies. The main contamination of soils is mainly spread in the northern direction. At the same time, maximum radionuclides concentrations are concentrated in the zone of crater bank and within the two-kilometer zone.

The nature of the areal distribution of radionuclides. Analysis of the data showed that contamination of the territory with ^{137}Cs is the most extensive (Figure 5) and spreads in all directions from the crater. At the same time, detectable levels (100 Bq/kg) of radioactive contamination are observed at a distance of up to 5 km from the crater.

Ground contamination with ^{241} Am is not so large-scaled and at a 2 km from the crater is already falls to the minimum detectable activity level of the equipment used (Figure 6). Unlike ^{241} Am, the detectable level of contamination with ^{152} Eu radionuclide is observed at a distance of up to 3 km (Figure 7).

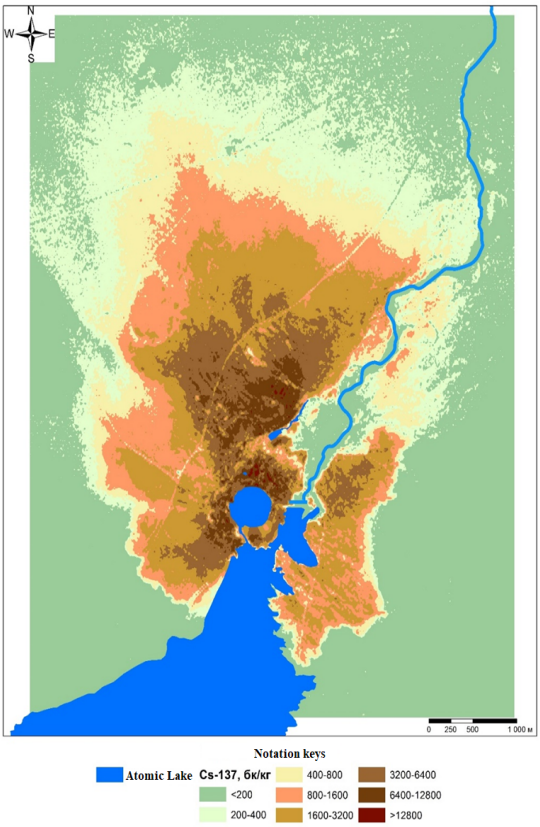

Figure 5. The nature of ^{137}Cs distribution.

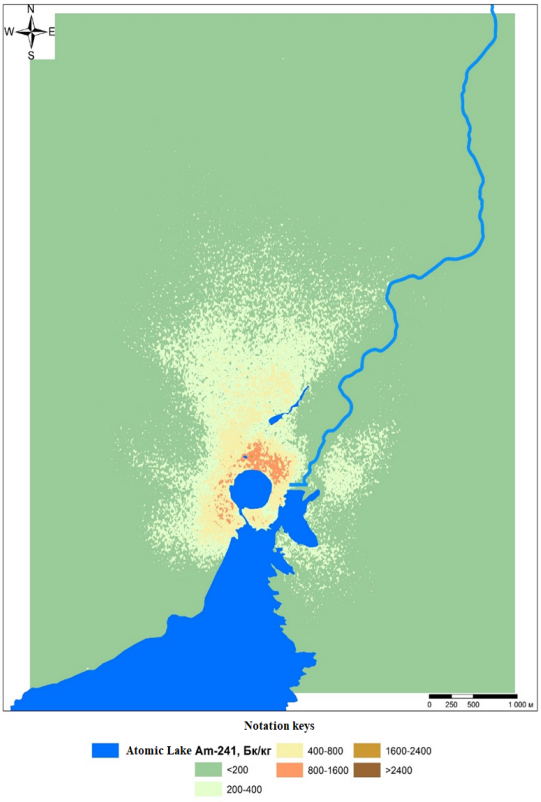

Figure 6. The nature of ^{241}Am distribution.

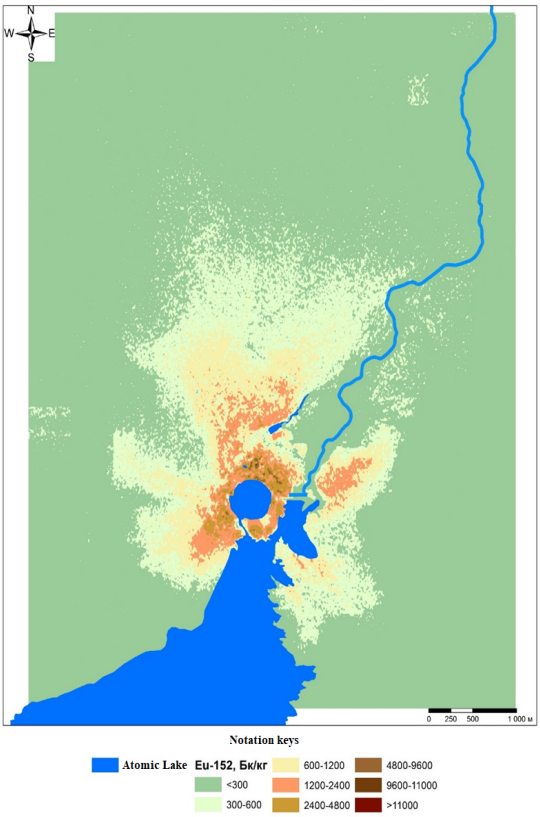

Figure 7. The nature of ^{152}Eu distribution.

The nature of the distribution of radionuclides in vertical profile at the crater bank. Figure 8 shows the nature of the artificial radionuclides distribution in vertical profile at the crater bank of the "Atomic" lake.

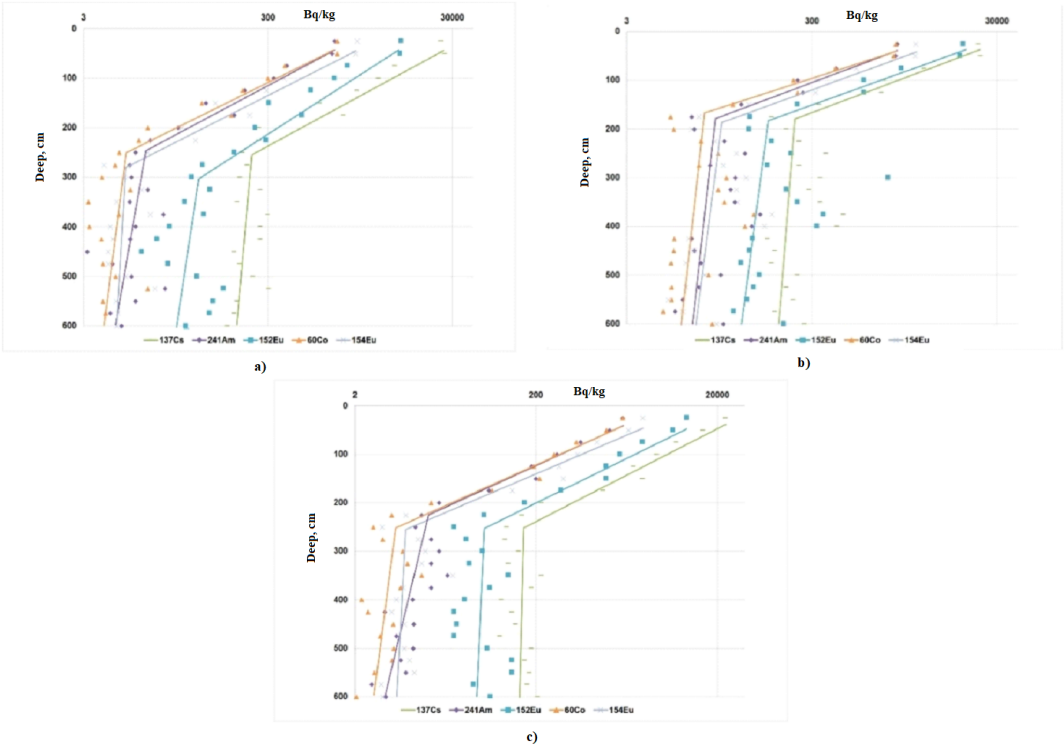

Figure 8. The character of the artificial radionuclides vertical distribution (bank).

The distribution of artificial radionuclides at the crater bank at all points is the same, and two zones are clearly distinguished. The first zone, with the thickness up to 200 cm, is characterized by exponential fall of activity by 1-2 orders of magnitude. In the second zone (200-600 cm thick) the activity remainsvirtually unchanged (Figure 8b).

The character of radionuclides vertical distribution in certain areas. Figure 9 shows the vertical distribution of artificial radionuclides in the area of external water reservoir.

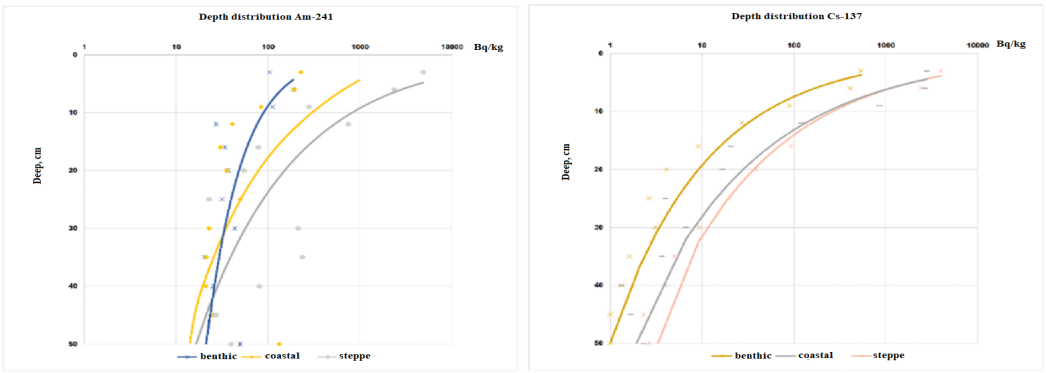

Figure 9. The character of the artificial radionuclides vertical distribution (external water reservoir).

Figure 10 shows the character of the artificial radionuclides vertical distribution at the flood plain of the Shagan river.

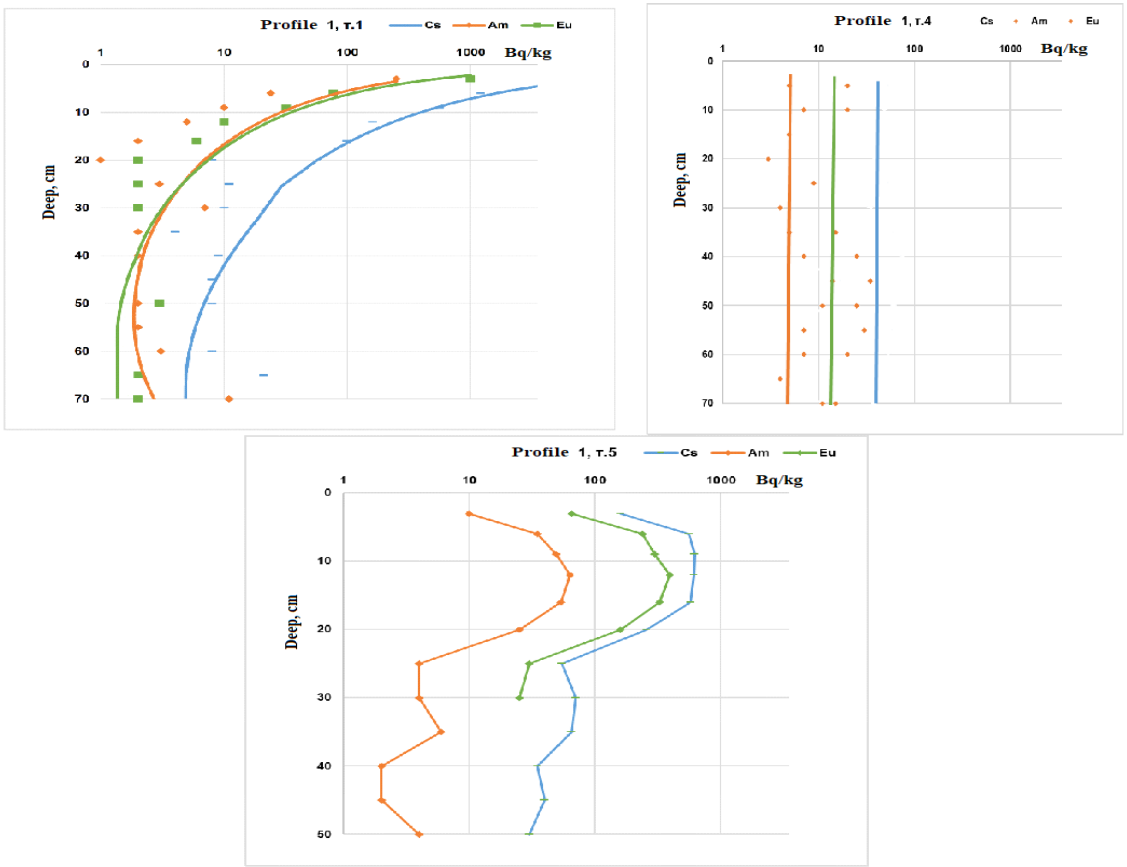

Figure 10. The character of the artificial radionuclides vertical distribution (flood plain of the Shagan river).

Figure 11 shows the character of the artificial radionuclides vertical distribution on the STS fallout plumes for comparison.

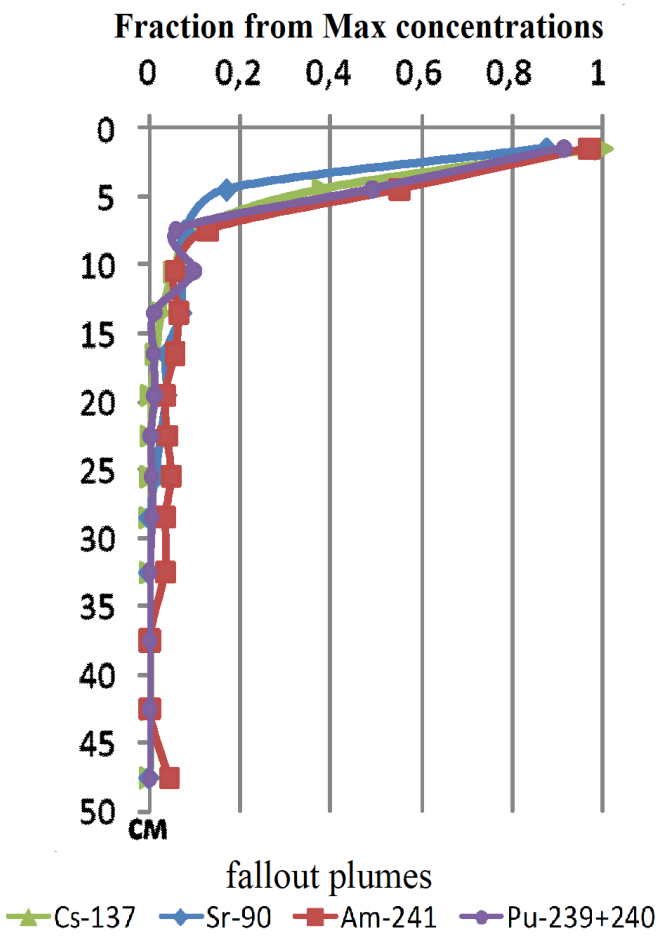

Figure 11. The character of artificial radionuclides distribution in certain areas of the STS).

As can be seen from the presented data, the character of artificial radionuclides vertical distribution in some parts of the "Atomic" lake territory is different. At that in spite of the different forms of the curves, virtually in all cases, the maximum concentrations of radionuclides werefound in the top 10 cm layer. Special attention should be paid to the distribution of radionuclides in the area of the flood plain of the Shagan river. Here, the concentration of radionuclides virtually does not vary over the entire depth, which is most likely due to the presence of a significant infiltration flow deep into the soil, which leads to equalization of radionuclide concentrations in the upper and deep horizons.

The nature of ^{3}H, $^{239+240,238}Pu$, ^{90}Sr, ^{137}Cs, $^{152,154}Eu$, ^{241}Am *contamination.*

The results of determining ^{3}H, $^{239+240,238}Pu$, ^{90}Sr, ^{60}Co, ^{154}Eu and ^{152}Eu artificial radionuclides and the average ratio values are presented in Figure 12.

Analysis of the data presented in the table shows that the isotopic ratios between the fission products, the products of activation by the neutrons of environment, the unreacted part of the charge in some parts of the territory of the “Atomic” lake are on the average practically identical. The average isotopic ratio of radionuclides $^{239+240}Pu/^{241}Am$ is 4.5, $^{238}Pu/^{239+240}Pu$ – 0.34, and

№	Sampling points	Sampling places	^{137}Cs	^{3}H	^{90}Sr	$^{239+240}$Pu	^{238}Pu	^{241}Am	^{152}Eu	^{154}Eu	^{60}Co	$^{239+240}$Pu / ^{241}Am	^{238}Pu / $^{239+240}$Pu	^{60}Co / ^{152}Eu	^{137}Cs / ^{241}Am	^{137}Cs / ^{90}Sr
			Activity, Bq/kg													
1.	A1	Bank	10000±1000	150000±15000	10000±1500	17000±1500	7500±700	3000±300	460±90	1500±300	1000±200	5,8	0,39	2,2	3,3	1,0
2.	A2	100m from bank	6400±1300	60000±6000	7400±700	1800±200	710±70	370±70	2100±400	760±70	500±50	4,9	0,36	0,24	17,0	0,9
3.	A3	160 m from bank	3100±600	23000±2300	2500±200	500±50	180±20	100±10	730±150	230±20	150±20	5,0	0,27	0,21	31,0	1,2
4.	A4	230 m from bank	13000±3000	57000±5700	12000±1000	2700±200	740±70	600±160	3200±600	1200±100	800±80	4,5	0,28	0,25	22,0	1,1
5.	A5	300 m from bank	14000±3000	97000±9700	11000±1000	2500±200	710±70	500±100	2700±500	1000±100	680±60	5,0	0,33	0,25	28,0	1,3
6.	A6	370 m from bank	5600±1100	9600±900	1500±100	200±20	60±6	120±20	930±180	360±30	240±20	1,7	0,40	0,26	47,0	3,7
7.	A7	470 m from bank	12000±2000	65000±6000	8900±900	2100±200	840±80	340±70	440±90	890±90	590±50	6,2	0,29	0,25	35,0	1,3
8.	A8	670 m from bank	3200±600	12000±1200	2100±200	320±30	90±9	70±15	760±150	150±20	110±10	4,4	0,32	0,25	44,0	1,5
9.	A9	1070 m from bank	7100±1400	25000±2500	4100±400	500±50	160±20	120±20	410±80	280±30	190±20	4,2	0,39	0,25	59,0	1,7
10.	A10	1470 m from bank	6400±1300	12000±1200	4100±400	280±20	110±10	90±10	150±20	150±20	110±10	3,3	0,33	0,27	74,0	1,6
11.	A11	1870 m from bank	920±180	3600±300	1700±100	60±6	20±2	-	40±10	<40	20±2	-	0,29	0,55	-	0,5
12.	A12	2270 m from bank	910±180	2300±200	650±60	100±10	30±2	-	40±10	<40	20±2	-	0,31	0,65	-	1,4
13.	A13	2670 m from bank	1300±200	4300±400	8500±800	90±9	30±2	-	40±10	40±5	30±3	-	0,39	0,70	-	0,2
												Average ratio				
												4,5	*0,34*	*0,48*	*36,0*	*1,4*

Figure 12. Specific activity and ratio of certain radionuclides.

^{152}Eu/ ^{60}Co is 0.48, ^{137}Cs/ ^{90}Sr – 1.4. In a number of places, this ratio has been disturbed, which is quite possible due to inaccuracies in field and analytical research, as well as technogenic disturbance of the soil cover. Therefore, the contamination of the "Atomic" lake territory with these radionuclides can be characterized by one value (Figure 13). However, isotopic ratios of the fission products to the charge material do not have stable values and are range within the interval from 3.3 to 74. At the same time, a regular decrease in the values of ^{137}Cs/ ^{241}Am ratio is observed all along the way from the crater of the "Atomic" lake (Figure 14).

Discussion of results

Upon the results of works, a contemporary picture of radioactive contamination of the territory adjacent to the "Atomic" lake was obtained. The nature of surface contamination, radionuclides distribution in depth on certain areas were determined. It was found that:

1. The surveyed territory is contaminated with the following radionuclides:
- fission products – ^{137}Cs, ^{90}Sr;
- products of activation by neutrons of the environment – ^{60}Co, ^{152}Eu, ^{154}Eu, ^{3}H;
- with unreacted part of the charge substance – ^{238}Pu, $^{239+240}$Pu, ^{241}Am.

2. The main radioactive contamination, as expected, is spread in north-, north-east direction from the crater. The maximum concentrations are on the crater bank in epicentral area. Therewith, underwater gamma-survey showed that the maximum concentrations are also confined to the bank. With distance

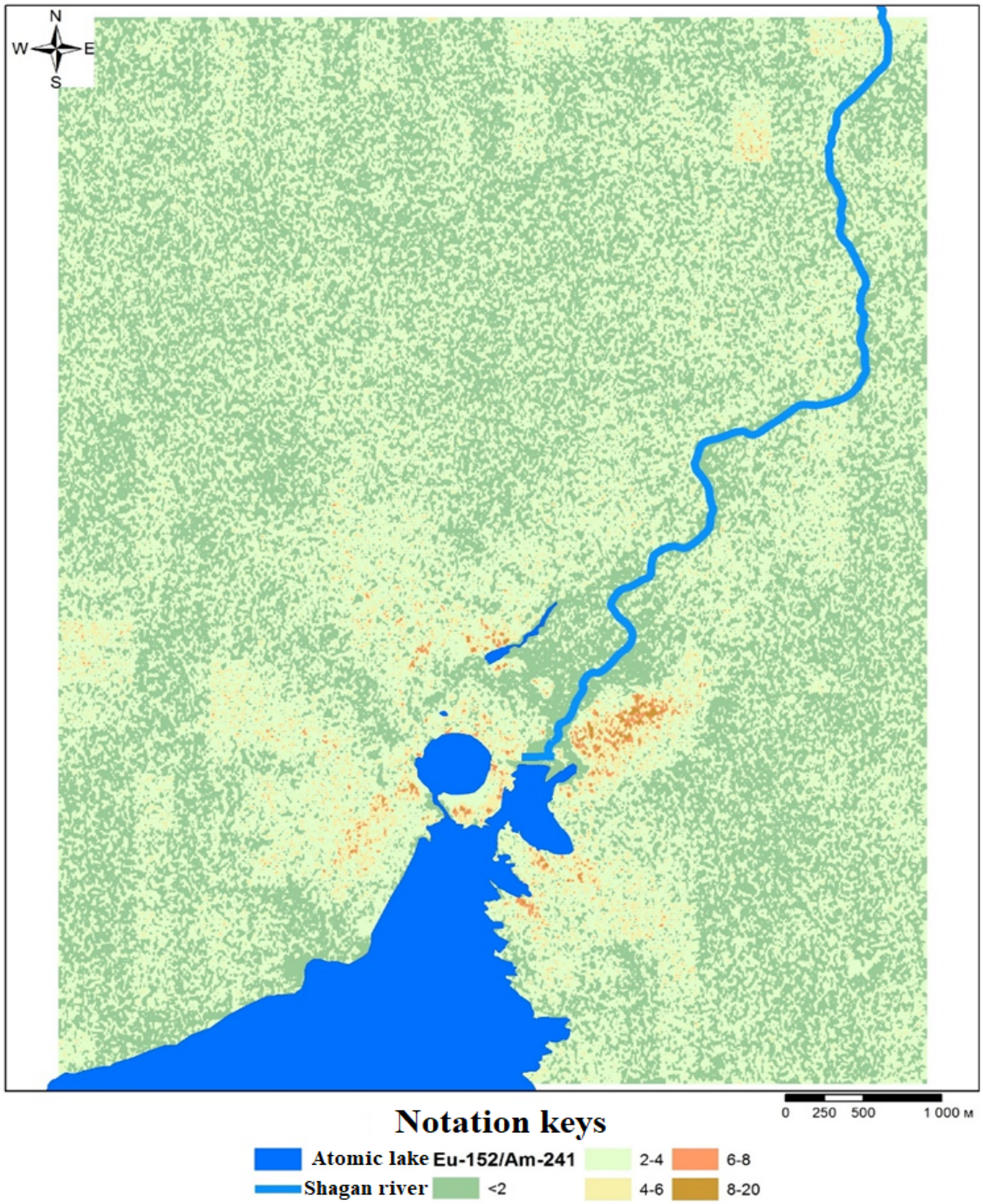

Figure 13. Distribution of isotopic ratio ^{152} Eu to ^{241} Am.

from the crater, the concentration of radionuclides decreases significantly, even to background ones at a distance of about (8 – 10) km.

3. Vertical distribution of radionuclides in most cases has traditional nature, i.e. maximum concentrations are found in the surface layer. The only exception is the areas that are subject to seasonal flooding. At these areas, because of intensive infiltration, there was a significant redistribution of radionuclides to depth.

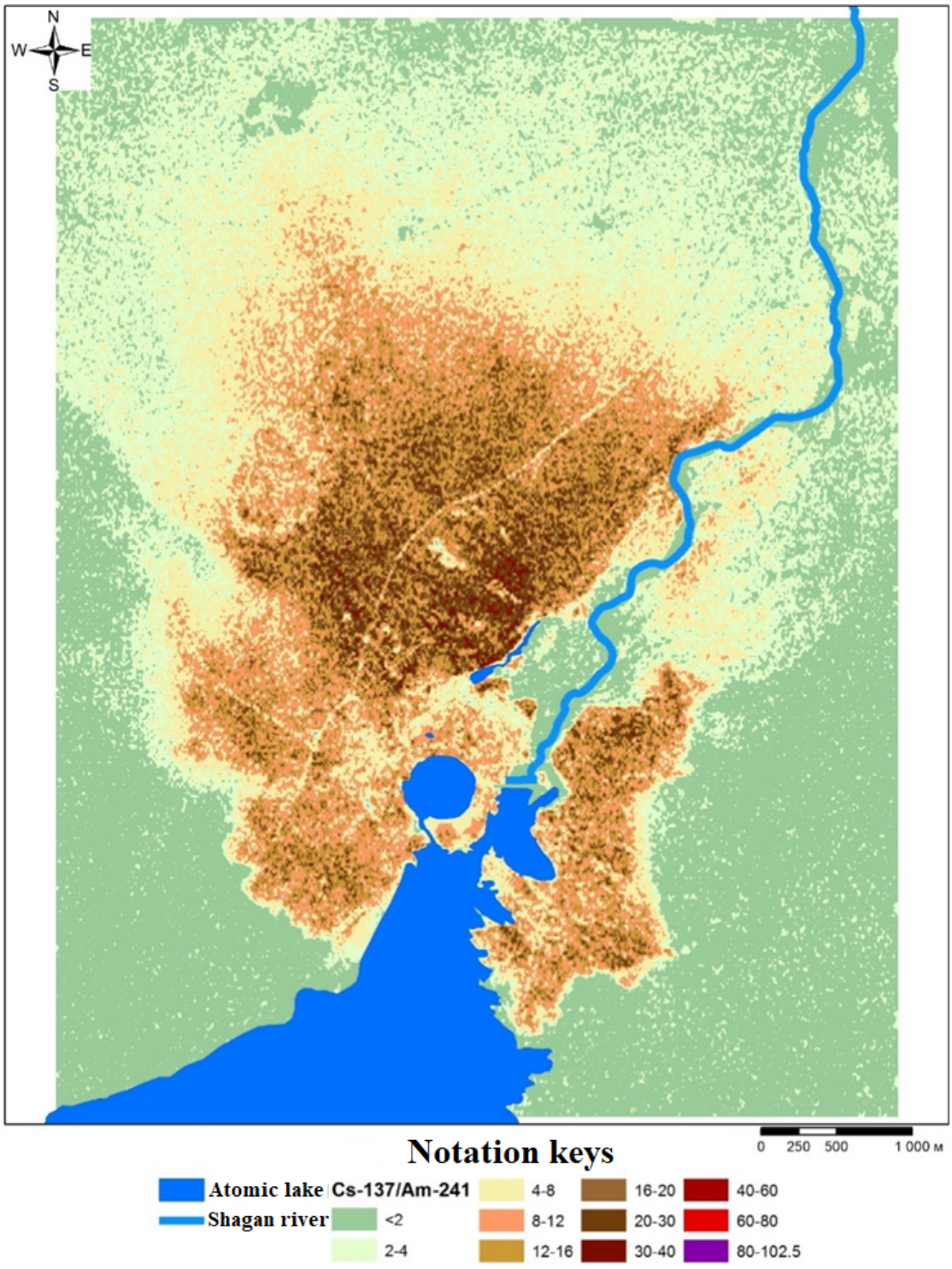

Figure 14. Distribution of isotopic ratio ^{137}Cs to ^{241}Am.

Conclusions

Upon the results of the research it was established that the excavation explosion in borehole 1004 had the most significant impact on the radioactive contamination of the investigated territory. At the same time, a slight contribution could be made by the fallouts from the tests made at the "Experimental Field". The works carried out did not reveal any correlation between the nature of territory

contamination and the traces from the tests at the “Opytnoe pole” site. This allows concluding that there is no significant effect of these tests.

It should be noted, that the areal distribution of radionuclides in this territory and plumes of tests in borehole 1004 are in no way interconnected. Based on which, we can make the assumption that, most likely, radioactive contamination was formed immediately at the first moment after the explosion.

With that, the contamination of this territory can be characterized by a single value of isotope ratios.

References

[1] Logachev V.A., Voloshin N.P., Dubasov Yu.V., Kornilovich E.P., Peaceful Nuclear Explosions: Providing General and Radiation Safety during These Operations (Moscow: IzdAT Publisher, 2001) 319 p.
[2] Ptickaya L.D., Assessment of the radiological situation and monitoring at the territory of Semipalatinsk test site and adjacent to it regions. Development of environmental protection activities. Assessment of the radiological situation at the test site "Balapan":report about scientific-research work (informative) / Institute of Radiation Safety and Ecology of NNC RK (IRSE NNC RK) (Kurchatov:IRSE NNC RK,2000) 16 p.
[3] GOST 17.4.4.02.84. Methods of selection and preparation of samples for chemical, bacteriological, helminthological analysis. - Introduction. 1986 - 01 - 01 (M: Publishing Standards, 1998) 48-54.
[4] Methods for performing measurements of the activity of plutonium radionuclides - 239, 240 in counting samples prepared from environmental samples. - (Moscow:FSUE "Research-And-Production Association V.G. Khlopin Radium Institute").
[5] Water quality - determination of tritium activity corresponding to a given concentration - liquid scintillation counting method: International Standard ISO 9698: 1989 (E). - Intro.1989-12-01.- (Moscow: VTsPNTLID, 1990) 17 p.
[6] Activity of radionuclides in bulk samples. The procedure for performing measurements on a gamma spectrometer MI 2143-91: - Enter. 1998-06-02. - Reg. ą 5.06.001.98. (Moscow: NPO VNIIFTRI, 1991) 18 p.
[7] Procedure of radionuclides activity measurement using scintillation beta spectrometer with software "Progress" (Mendeleevo, 2004) 20 p.