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Issue 4

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Reviewers:

1. **Kadyrzhanov K.K.** – Advisor to the Rector for Science, L.Gumilev Eurasia National University, Doctor of Sc. in physics and mathematics, Professor, Academician (Astana, Kazakhstan)

2. **Solodukhin V.P.** – Leading scientist, head of Radioecology division at the Center for Complex Ecology Research of the Institute of Nuclear Physics NNC RK, Doctor of Sc. in physics and mathematics (Almaty, Kazakhstan)

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The issue covers works of the National Nuclear Center of the Republic of Kazakhstan performed mainly in 2011-2012. The papers are devoted to the issues of radioecological conditions at the former Semipalatinsk Test Site and adjacent territories, safety assurance of the works at STS, non-radiological hazards, and general issues of radiation safety assurance at some other objects and sites in Kazakhstan. We hope that this volume provides interested reader with reliable and high-quality information on real present state of the former STS and helps everyone in forming unbiased view on this unique facility called Semipalatinsk Nuclear Test Site.

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CONTENT

Volume 1

To the 20th anniversary
of the Institute of Radiation
Safety and Ecology
of the National Nuclear Center

EDITOR'S FOREWORD

Dear reader,

This issue we devote to the 20th anniversary of our Institute of Radiation Safety and Ecology (IRSE) under National Nuclear Center of the Republic of Kazakhstan (NNC RK).

The Institute has been established during difficult for the country times which, naturally, were even more dramatic for the newly organized Institute. At that, the society set a very difficult social task to National Nuclear Center and to our Institute as its integral part: it was necessary to find answers to a range of sensitive, urgent and important for people in Kazakhstan questions about present radioecological situation at former Semipalatinsk Nuclear Test Site STS and adjacent territories and how dangerous STS is in its present status. At that, the answers provided were expected to be of good probative evidence to make people in Kazakhstan trust them.

So, what is IRSE now? From one side, this is a recent formation of "official age" of 20 years and average age of employee about 30 years; from the other side, IRSE is, to certain extent, a successor of the Testing-and-Research Sector of the military unit 52605, that particular legendary unit established in 1948 which did scientific and technical assurance of all tests performed at the former Semipalatinsk Nuclear Test Site (SNTS).

Our people is the main asset of the Institute. Surprisingly, we face no workforce ageing problem since all leading researchers are still younger than 35; at that many of them lead whole areas of radioecological research and studies in the field of radiation safety.

I would like to note some of them: Osintseva A.Yu., Mustafina Ye.V., Korovina O.Yu., Kashirsky V.V., Umarov M.A., Salmenbayev S. (the head) in the radiology studies and ecosystem rehabilitation department who increased the scopes of the field research in the last 6-7 years not for mere 20-30%, but for orders of magnitude with dramatically increased quality of analytical work if we speak in terms of range of determined radioisotopes and analyzed objects, range of determined concentrations; Aidarkhanov A.O., Lyakhova O.N., Aktayeva M., Turchenko D.V. (the head) in the department for environment monitoring systems who gained entirely new data on tritium contents in STS environmental objects, studied scopes and ways of radioactive isotopes' migration within STS, and mastered in several new methods for studies of migration processes; Panitsky A.V., Larionova N.V., Kabdyrakova A., Kunduzbayeva A., Baigazinov Zh., Kozhakhanov T.E. who valuably contributed into the understanding of transition processes of the radionuclides (including transuranium ones) in the chain soil – plants (wild and cultivated) – agricultural animals, and who designed a set of unique field experiments on STS lands; Subbotin S.B., Yakovenko Yu. (the head) in the group of geoinformation systems and other people who made it possible to plan the works, analyze and generalize the obtained data and huge amounts of information about STS gained in our vast research.

Still, our bright junior scientists are not the whole Institute. Yes, they are on the top of the pyramid, but their effective work is provided by quiet, well-organized and reliable day-to-day backup by administrators, economists, drivers, artificers, interpreters and many others whose names are not among the authors of scientific papers and monographs, but who also make the research happen. I have to name here Dmitropavlenko V.N., Shmurygin V.G., Kadyrov N.Zh., Boltovskaya N.F., Strilchuk Yu.G. Seraya O.V., Tonevitskaya O.V. since our scientific success is the success of the whole team. Thanks to their hard work we run new facilities and better premises, purchase equipment, we get heat in winter and can enjoy walking down the Institute's site.

One more important component in the Institute's progress is the long term partnership with other research centers in Kazakhstan and, particularly, with Institute of Nuclear Physics in Almaty (INP). Cooperation with this institute allowed our researchers to quickly cover the long way from juniors to masters and the effective joining of our efforts allowed us to solve such state-level tasks as comprehensive studies of vast STS territory with the purpose to transfer the lands for commercial utilization. With this regards, I would like to express deep gratitude to INP management – Tuleushev A.Zh., Chakrov P.V., and its key workers Gluschenko V.N., Solodukhin V.P., Kiyatkina N.G., Kharkin P.V.

The history of our Institute had several periods – formation, development, and now – the period of active growth. In the last years we considerably changed and upgraded our instrumentation, improved infrastructure what was only possible with continuous care, overall support and even encouraging trust by our umbrella organization National Nuclear Center of the Republic of Kazakhstan and its Directors – Kadyrzhanov K.K. and Batyrbekov E.G. Comparing our laboratories with similar laboratories worldwide allows us to understand that in certain fields we are on the frontiers of modern research what is supported by publications of our outcomes in the world's leading journals and by the level of dissertations prepared here.

Now we can say with confidence that the objectives set for the Institute have been achieved. The mammoth amounts of information about current radiological situation at STS and adjacent territories have been obtained. There were revealed all important areas of radioactive contamination, main pathways and mechanisms for present or potential proliferation of radioactive substances. Of course, taking into account the scales of STS and the variety of tests performed here, the information collected is not yet totally comprehensive but is enough for elaboration of a scientifically ground plan for cardinal solutions of STS problems. As a result of these works, we envisage to adjust the administrative border of the STS with its real present-day radiological state. We are also keen to finally eliminate the most hazardous in radiological terms sites by the 30th anniversary of the State independence.

For sure, in the future the Institute will keep focusing its activities on STS issues, but at the same time, the Institute recognizes its responsibility for resolving other radiation-related problems in Kazakhstan. First of all, our attention is attracted by the problem of establishing a unified State system for accounting and control of doses for personnel and population with technical, engineering, methodical and staff issues involved.

We identify our current mission as "Development and realization of scientifically ground measures and activities for lowering of collective dose on Kazakhstani population down to minimal possible levels."

Regarding the content of the present issue, we present here the outcomes of the works performed in 2011-2012 which were equally devoted to studies of present state of STS objects and environment and to studies of fundamental of the processes here. Besides that, several papers brief into other objects in Kazakhstan with radiological hazards: these are sites of so-called peaceful nuclear explosions at Usturt Plato, Meridian-3 facility and the spent nuclear fuel storage of IGR reactor.

Welcoming you on these pages, one thought comes to my mind: we surely have radioecological challenges in Kazakhstan, but we are sure to overcome them.

NNC RK Deputy Director General for Radioecology and Director of the Institute of Radiation Safety and Ecology NNC RK  **Lukashenko S.N.**

PART: RADIOECOLOGICAL SITUATION AT THE FORMER SEMIPALATINSK TEST SITE AND ADJACENT TERRITORIES

УДК 577.4:577.391: 504.73:539.16

RADIOECOLOGICAL CONDITIONS AT THE SOUTHEASTERN PART (SARZHAL VILLAGE REGION) OF THE SEMIPALATINSK NUCLEAR TEST SITE

[1] Strilchuk Yu.G., [1] Lukashenko S.N., [1] Kashirsky V.V., [1] Yakovenko Yu.Yu., [1] Aidarkhanov A.O., [1] Lyakhova O.N., [1] Larionova N.V., [1] Magasheva R.Yu., [1] Panitskiy A.V., [1] Subbotin S.B., [1] Kunduzbaeva A.E., [1] Toporova A.V., [1] Tonevitskaya O.V., [2] Bakhtin L.V.

[1]Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan
[2]Institute of Geophysical Research NNC RK, Kurchatov, Kazakhstan

The paper presents the outcomes of radioecological survey of southeastern part of the Semipalatinsk Test Site (STS), located in Sarzhal village area, on 850 km^2 area. Within the study area the modern radiological condition of the environmental objects: soil, water bodies, air basin, vegetation, animal life were evaluated. The territory can be divided into three zones by levels of artificial radionuclides ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in soil. Elevated levels of radionuclides in the soil in two zones are due to the tests carried out at the STS. The average specific activities of ^{137}Cs and ^{90}Sr in soils throughout the study area are at the background of global fallout, or slightly (1.5 times) exceeds it. The average specific activities of $^{239+240}$Pu are 1.5-6 times higher than the background of global fallout.

Based on the data on the content of radionuclides in the environment and food we estimated dose loads to the population. Provided a "worst case" scenario "Subsistence farmer on contaminated area", the expected annual effective dose for humans will be 0.08 mSv, which does not exceed 0.3 mSv and a lower than intervention level, according to the Hygienic Standards "Sanitary Requirements for Radiation Safety". Based on the comprehensive examination and the expected doses to the population, in accordance with existing regulatory requirements of the Republic of Kazakhstan, the entire surveyed area can be used without restriction.

These studies were conducted in order to further transfer the lands to civilian use.

Keywords: nuclear testing, radioecology, radioactive contamination, radionuclides, vegetation, water objects, behavior scenarios, dose loads.

INTRODUCTION

In 2008-2010, the Institute of Radiation Safety and Ecology carried out complex ecological investigations in the "northern" and "western" STS territories of the total area of 3,560 km^2. In 2010-2011, in response to the appeal of the villagers of Sarzhal village, the National Nuclear Center of the Republic of Kazakhstan chose the territory of the "southeastern" STS part of an area of 850 km^2 located near the village of Sarzhal as a priority area for complex ecological investigations. The priority area included the territory of pastures named in the villagers' letter (Figure 1). The subject of the research was the environmental objects: vegetation soil cover, water, air and wild animals.

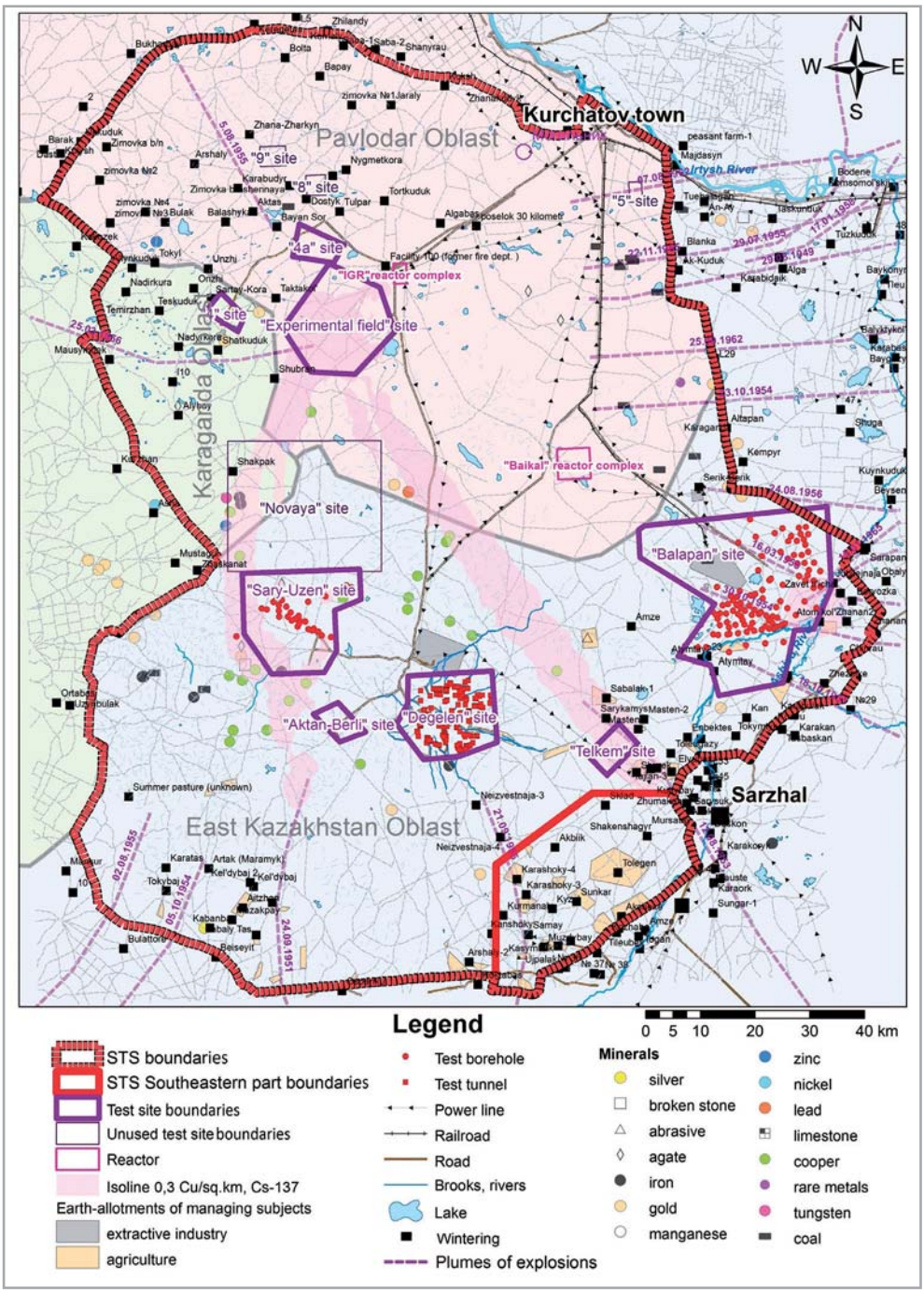


Figure 1. Map of the area

The studied area is located on the northeastern slope of Balkhash-Ili watershed and in geographical terms is a part of Kazakh Hummocks. This area is characterized by extremely continental arid climate. Air temperatures vary widely with high differences in day-and-night and summer-and-winter temperatures. Strong winds mainly blow in spring (April, May) and in February and October with maximal wind speed 35-40 m/s. The greatest number of calm days is observed in summer and in early autumn. Very strong and long-drawn winds, the speed of which exceeds 20-30 m/s, may cause dust storms [1]. Soil particles easily rise from dry rough surface with rare vegetation in conditions typical of arid and semi-arid areas, where undulating ground and destruction of soil cover by cattle grazing, automobiles and anthropogenic activities enhance dust rise by wind. Dust storms are most often observed from May to July. The average wind speed during dust storms varies from 15 to 20 m/s.

The studied area can be referred to areas with insufficient precipitation. It is explained by the fact that Eurasian barometric circulation regime mainly provides inflow of arctic air and continental air from middle latitudes with low humidity. Aridity of local climate is also intensified by the influence of deserts of Central Asia and southern Kazakhstan. The annual amount of precipitation varies from 117.4 to 275.0 mm with maximal values in summer. The barometric circulation regime in the warm part of the year creates favorable conditions for significant precipitation from May to August, when 50-60 % of the annual amount of precipitation fall out as shower rains. However, precipitations in the warm period are accompanied by high temperatures, which decrease their importance as a factor of air humidification. In the warm period of the year, when evaporation increases, natural soil moistening is not sufficient. In autumn as compared with summer rains the amount of precipitation is not high, but as the temperature in autumn is lower and evaporation is much lower, falling precipitations give sufficient moistening for soil.

Monitoring of anthropogenic activities on the studied area detected 12 inhabited and 2 uninhabited winter camps. The average number of people living in winter camps varies from 2 to 8, only in the village of Samay 70 people live. The main type of agricultural activity is animal farming (sheep, cattle, horses). All in all, there are about 270 cows, more than 2000 sheep and 200 horses. The owners of some winter camps are villagers of Sarzhal village, where the workshop for production of mare's milk – kumys is located.

On the studied area farmers mainly have outbreed hair sheep. In cattle farming they have low-productive outbreeds of meat and milk breeds. In horse-farming there are mainly outbreed horses, stud horses are not bred. The cattle is kept in stables and grazed on pastures. Cattle grazing is free and unrestricted. The pastures in the area are used all year round, however, there are some territories that are only used in summer period, where cattle grazing on natural pastures starts in the first decade of May and finishes at the beginning of October.

The main types of produced products are mutton, beef, horse meat, milk and kumys. The market areas are cities of Semey, Ust-Kamanogorsk, Almaty, Karaganda and adjacent populated centers.

There is practically no crop farming in the area except for growing rough fodder on pasture haylands. Succulent fodder growing (silage, haylage, root crops, etc) is not developed. The main type of produced rough fodder is hay, which is used as an additional feeding in the winter period and is the most important component of ration for providing full-fledged animal's feeding.

Prospects for the development of animal and crop farming

According to its natural characteristics (soil, vegetation, relief) almost all territory of the studied area refers to the category of pasture lands. Therefore, the most promising branch of agriculture is animal farming. However, unrestricted grazing causes degradation of vegetation cover and, as a result, food reserve as in this area pastures give not less than 80-90% of annual amount of feeding stuffs [2]. Provided scientifically-based development of pasture areas, it is perspective to develop animal-breeding farms growing traditional food-producing animals – sheep, cows and horses.

In order to cover needs of farmers growing cattle, it is possible to organize growing of vegetables in backyard gardens on the same farms.

Therefore a potential type of agricultural activity in the studied area is cattle farming based on the principle "a farmer working in his household". Crop farming can be developed in backyards organized on animal farms to provide needs of farmers in vegetables.

1. MAJOR MAN-CAUSED FACTORS FOR RADIATION CONDITIONS IN THE REGION

Analysis of available data showed that radiological conditions in the region could be mainly formed as a result of the tests on "Experimental Field" site:

- Surface nuclear test – the first surface test of 400 kiloton thermonuclear device, done on August 12. 1953.
- Model experiments (hydronuclear and hydrodynamic) conducted 22.07.61 and 26.09.63 (Figure 2).

According to the literature, only one nuclear test could affect the radiation environment in southeastern territories of the STS – it is 400 kt surface thermonuclear test of 12.08.53.

Given the above tables, the maximal possible activity of fission fragments in the study area will be the following values (Table 1).

Table 1.

Maximal possible activity of fission fragments in the southeastern part of the STS

Nuclide	Initial time		1.12.2011		25 years		50 years	
	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio
^{137}Cs	269	1	69	1	38.8	1	21.9	1
^{90}Sr	99	0.37	24.5	0.37	13	0.34	6.7	0.34
^{151}Sm	10.3	0.038	6.5	0.094	5.4	0.14	4.4	0.2
^{99}Tc	0.04	0.00014	0.04	0.00056	0.04	0.001	0.04	0.0018
$^{239}Pu + ^{240}Pu$	29.5	1	29.5	1	29.5	1	29.5	1
^{238}Pu	1	0.032	0.64	0.021	0.51	0.017	0.38	0.012
^{241}Pu	245	8.4	15.3	0.5	5	0.15	1.4	0.046
^{242}Pu	4.1×10^{-5}	1.4×10^{-6}	4.1×10^{-5}	1.4×10^{-6}	4.1×10^{-5}	1.4×10^{-6}	4.1×10^{-5}	1.4×10^{-6}
^{241}Am	-	-	6.7	0.25	8	0.28	8.1	0.28

Maximal possible activity of fission fragments in southeastern STS

^{241}Pu activity actually may be somewhat higher due to activation of ^{240}Pu by prompt neutrons, but the cross section of this reaction is very small to make a difference.

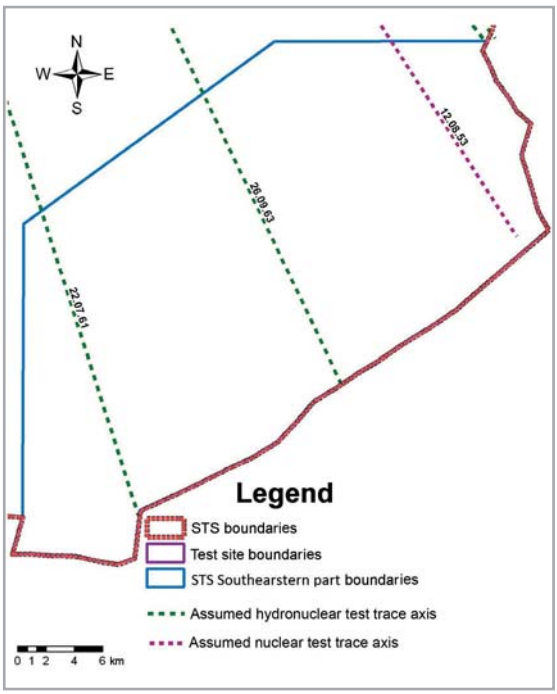


Figure 2. Axes of the radioactive plumes from surface nuclear and model experiments

When the amount of released nuclear energy at an explosion experiment with nuclear charge is comparable with the energy of chemical explosive less than 1 ton, such tests refer to the category of hydronuclear tests and do not refer to nuclear tests except the cases when such result occurred in a specially planned nuclear test.

From 1960 to 1965, 40 hydronuclear experiments were carried out on the technical ground P-2G of the "Experimental field" site. This ground is located 95 km away from the study area boundary. All experiments were conducted on the soil surface, mainly in 3 meter deep trench. The tests varied by amount of released activity into the atmosphere and a lifting height of the upper edge of the explosion cloud. The total amount of plutonium alpha activity dispersed during entire time of the hydronuclear experiments ranged from approximately 800-900 Curie, which could lead to radioactive contamination around the test site [1].The studied territory may be contaminated with plutonium only if the azimuth directions of the axes of test trails were located in the sector from 143° to 166° (southeast direction). According to the available data [2], of 24 tests which caused the main dispersion of plutonium only 2 tests had azimuth directions of plume axes 162°, 153° in which the length of the areas with plutonium contamination 0.1 Ci/km^2 could be 16 and 14 km, respectively, whereas at areal activity 2.25*10^{-2} Ci/km^2 could be 47.5 and 42 km. With such characteristics, perhaps, the two tests with the release of 41 and 45 Ci of plutonium, respectively, could contribute to the contamination of the study area with plutonium isotopes. Significant contribution to the contamination of the area these tests can be traced in the "Baitemir" field located 30 km from "Experimental field" site. Plutonium concentrations in the soil cover in the field may reach

hundreds or thousands of Bq/kg. It is possible that under certain weather conditions at the time of the tests they could contaminate the area even at a distance of over 90 km which is southeastern part of STS.

1.1. Methodology for assessment of contamination due to tests at the former STS

Surface contamination of the studied areas caused by the tests at the former Semipalatinsk Test Site can mainly be caused by the nuclear tests on the "Experimental Field" site, the place where surface and atmospheric nuclear tests were performed, as the tests in tunnels and wells gave very little contribution to the contamination of the environment (including the global scale).

Radionuclide contamination of the area adjacent to the test ground might have been caused by the following factors:

1. Radionuclides recovered from nuclear fission (fission fragments).
2. Remainders of the fission material.
3. Activation of nuclei in the environment by prompt neutrons.

1.2. General description of the model of surface distribution of contamination caused by nuclear AIR explosions

In order to estimate possible contribution of nuclear tests to the surface contamination of the studied areas we used a "classical" model of formation of radioactive plume zones as a result of nuclear explosion. [5].

The 12.08.53 test is thermonuclear device detonation in which fissile material ^{239}Pu only acts as a fuse. Thermonuclear fusion is a fusion of two hydrogen isotopes – deuterium and tritium with release of large amounts of energy. Therefore, the main power of the explosion accounts for fusion, not fission of ^{239}Pu. Thermonuclear fusion do not form long-lived radionuclides such as ^{90}Sr and ^{137}Cs. Fissile material residue activity and fission fragments in the study area are determined only by the fuse mass. Activation products are not considered in the calculations due to the remoteness of the areas considered from testing site.

To determine the mass of ^{239}Pu in a thermonuclear charge soil was sampled on radioactive trail, formed after the test. Total number of samples was 796. Average ^{137}Cs activity was 600 Bq/kg. The trail, according to the GIS laboratory, is 676 km^2. Given the soil density 1400 kg/m^3 sampling depth of 0-5 cm and half-life, the mean absolute activity of ^{137}Cs on the trail area is 774 Ci.

Reference [6] gives the activities of ^{239}Pu fission fragments in Ci/kt at different moments after the explosion. According to the data, the mean absolute activity of ^{137}Cs – 774 Ci is consistent with 15 kt nuclear explosion.

Based on dependencies of radiological contamination spots as a function of explosion yield, we calculated linear dimensions for the areas or radiological contamination due to the 400 kt fusion explosion. According to the calculations, predicted for the next 50 years activity from the decay products at the studied territories may be as indicated below (see Table 2).

Table 2.

Maximal possible activity of fission fragments in the southeastern part of the STS

Nuclide	Initial time		1.12.2011		25 years		50 years	
	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio
^{137}Cs	269	1	69	1	38.8	1	21.9	1
^{90}Sr	99	0.37	24.5	0.37	13	0.34	6.7	0.34
^{151}Sm	10.3	0.038	6.5	0.094	5.4	0.14	4.4	0.2
^{99}Tc	0.04	0.00014	0.04	0.00056	0.04	0.001	0.04	0.0018

The amount of nuclear charge of the fissionable substance remained by the moment of destruction of the construction is determined by the efficiency of nuclear explosion η, which depending on the type and construction of the nuclear device may vary from 1 to 30%. In further calculations this figure, because of the absence of official data for each explosion, is taken equal to 20%.

Further, knowing typical isotope composition of weapon Pu, it is not difficult to calculate activities of its other isotopes present in the charge substance. This method was used to calculate activities of all Pu isotopes taking into account their half-life period at the initial moment of time and at the present time; it was also used to estimate variations in Pu concentrations in the next 25 and 50 years. Calculated maximal possible activities from decay products at studied territories would comprise the values (Table 3).

Table 3.

Maximal possible activity of fission fragments in southeastern part of the STS

Nuclide	Initial time		1.09.2011		25 years		50 years	
	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio	Bq/kg	Ratio
^{239}Pu + ^{240}Pu	29.5	1	29.5	1	29.5	1	29.5	1
^{238}Pu	1	0.032	0.64	0.021	0.51	0.017	0.38	0.012
^{241}Pu	245	8.4	15.3	0.5	5	0.15	1.4	0.046
^{242}Pu	4.1×10^{-5}	1.4×10^{-6}	4.1×10^{-5}	1.4×10^{-6}	4.1×10^{-5}	1.4×10^{-6}	4.1×10^{-5}	1.4×10^{-6}
^{241}Am	-	-	6.7	0.25	8	0.28	8.1	0.28

^{241}Pu activity actually may be somewhat higher due to activation of ^{240}Pu by prompt neutrons, but the cross section of this reaction is very small to make a difference.

2. COMPREHENSIVE ENVIRONMENTAL STUDIES

In developing the plan for areal survey the following key factors have been considered:

- availability of information on the content of radionuclides in the soil of the study area;
- recommendations of the IAEA expert group (1 km grid is proposed for surveys);
- basic regularities of radioactive contamination from nuclear tests (possible contamination spots characteristic dimensions, sampling depth).

General concept for survey

Field work was conducted on the territory of the former Semipalatinsk Nuclear Test Site by daily visit to the site surveyed. There surface soil was sampled on 1x1 km grid. After the preliminary findings obtained two additional sites for research on 500 m grid were identified (Figure 3).

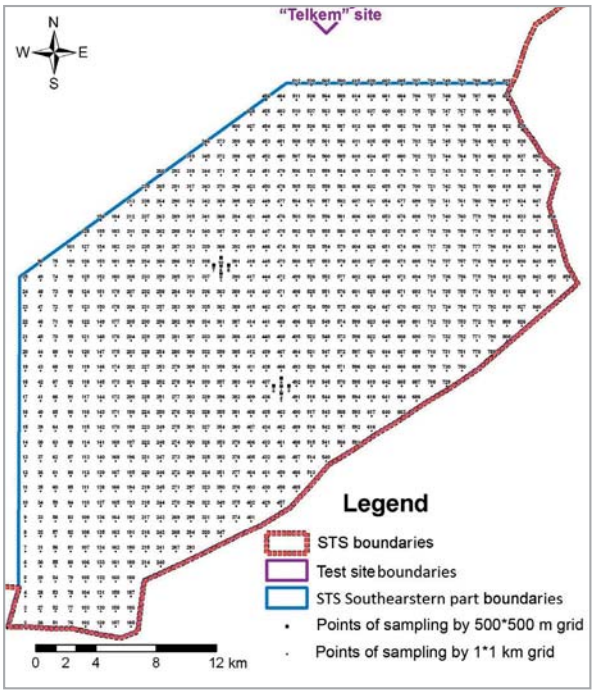


Figure 3. Survey of the STS southeastern part (Sarzhan village area)

The samples were taken pointwise (dotted) from the 100 cm^2 at a depth of 5 cm. Weight of a taken sample is about 1 kg. At each sampling point we determined geographic coordinates and measured integral radiation characteristics: gamma radiation equivalent dose rate at 1 m height and the beta particles flux density from the surface layer of soil. The sampling data were recorded in field book (journal). The coordinates were recorded in the system WGS84; values are represented as degrees, minutes and seconds. Each sample was placed in a double plastic bag with a label. The labels indicate code of sample, EDR readings and the flux density of beta radiation.

The field operations took 868 soil samples. The mean radiation parameters are shown in Table 4.

Table 4.

Mean radiation parameters in the area studied

Site№	γ_{max}, μSv/h	γ_{min}, μSv/h	γ_{cp}, μSv/h	β_{max}, particle/(min×cm²)	β_{min}, particle/(min×cm²)	β_{cp}, particle/(min×cm²)
Site № 1	0.17	0.05	0.10	25	<10	10

The radiation parameters were measured by:

- Dosimeter-radiometer DKS-96 ABG, № 146. № 024 2003 (beta radiation flux density measurement range is from 10 to 10^5 $min^{-1} \times cm^{-1}$);
- Dosimeter SRP-68-01. № 1534. 798;

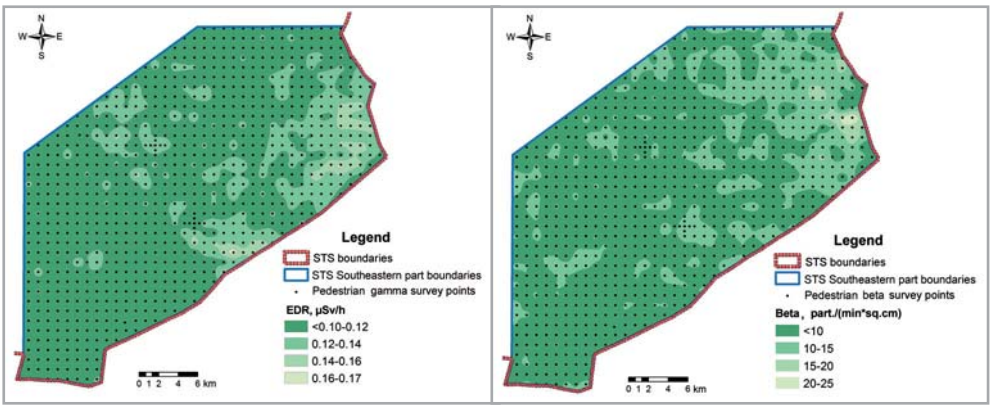
All gauges were subjected to metrological verification.

All samples were packaged, labeled and transported to the laboratory for investigations. After preliminary preparation (drying, sieving, quartering) the samples were analyzed for major gamma-emitting radionuclides of both natural (^{232}Th, ^{40}K, ^{226}Ra) and artificial (^{137}Cs, ^{241}Am, ^{60}Co, ^{152}Eu). Part of the samples was then forwarded for radiochemical analysis to isolate and determine ^{90}Sr, $^{238, 239+240}$Pu. The samples with $^{238\ 239\ +240}$Pu identified, as a rule, were re-analyzed for ^{241}Am, which was determined after further homogenization of the sample to determine the ratio of these radionuclides.

2.1. Distribution of integral parameters

Radiation parameters (EDR and flux density of beta particles) were measured for a preliminary assessment of the radiation condition in the southeastern part of the STS. In total the radiation parameters were measured in 868 points. Depending on the area of research and tasks the survey density ranged from 1 measurement on 0.25 km^2 to 1 measurement on 1 km^2.

The results of EDR distribution and β-particles flux density in the study area are shown on Figure 4.



a) b)

Figure 4. EDR distribution (a) and β-flow density distribution (b) at the surveyed area

Assessment of radiological parameters at the southeastern part of STS showed that EDR corresponds to natural background values of the radiological parameters compared both with the world's average and average for Kazakhstan numbers; beta-particle flow slightly exceeds the background values. At the same time, distribution of radiological parameters in the central and north-eastern parts of the studied area revealed increased EDR and β-flow densities. Areas with increased readings correlate with the plume axes from the first ground fusion explosion (12.08.1953) and the model (26.09.63).

2.2. Areal radionuclide contamination of soils

2.2.1. Areal distribution of natural radionuclides

The main component of the radiation background in the study area is due to natural radionuclides which are in series of decay of uranium and thorium, and potassium (^{40}K). Of natural radionuclides we determined ^{40}K, ^{232}Th and ^{226}Ra. The natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra were determined in 868 soil samples collected from 0-5 cm surface horizon. The studies enabled to plot areal distribution map for ^{40}K, ^{232}Th and ^{226}Ra (Figure 5).

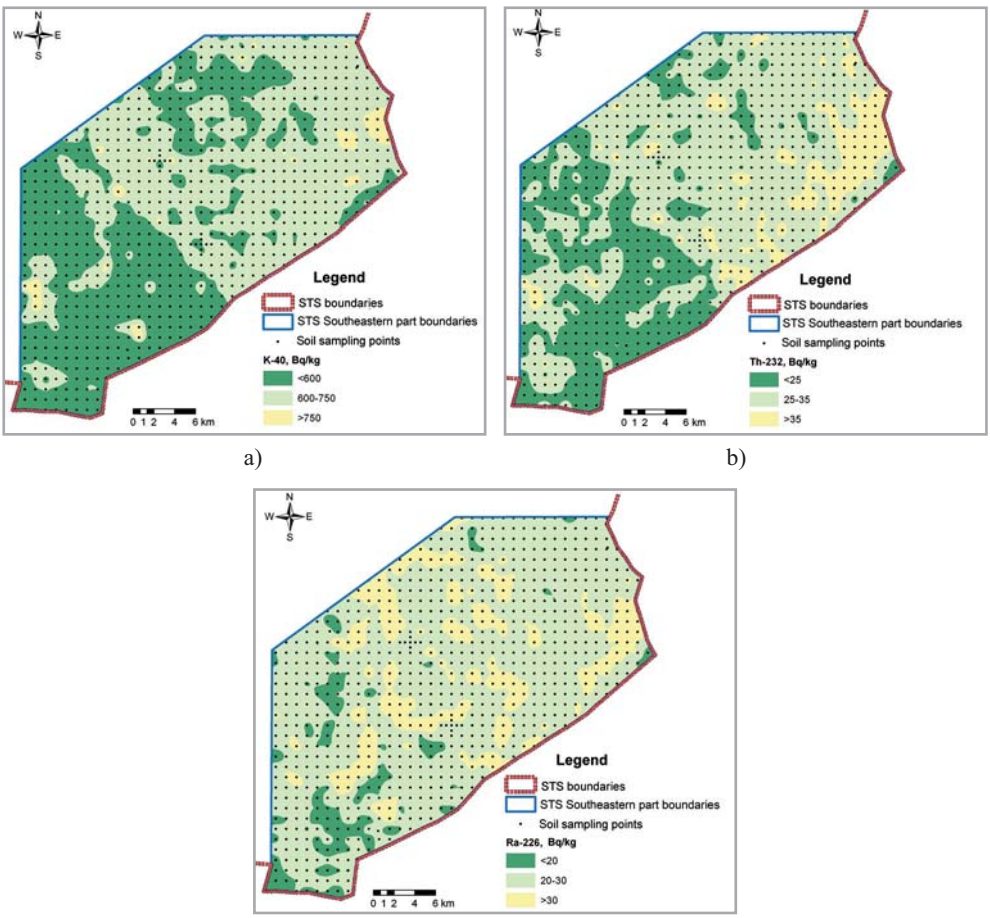


Figure 5. Distribution of ^{40}K, ^{232}Th, ^{226}Ra in soils of southeastern STS

For comparison of the results Table 5 provides maximal and minimal specific activities of natural radionuclides in soils of Kazakhstan, as well as their averages [7].

Table 5.

Activity of natural radionuclides in soils of Kazakhstan

Variation limit	Specific activity, Bq/kg		
	^{40}K	^{226}Ra (^{238}U)	^{232}Th
Minimal	100	12	10
Maximal	1200	120	220
Average	300	37	60
Territory studied	1031	72	51
Примечание: It is assumed that in the ores of uranium and thorium the radioactive equilibrium is close to one, specific activity of uranium and radium is equal			

In the samples of the study area the recorded maximal specific activity ^{40}K, ^{226}Ra and ^{232}Th does not exceed the maximum for the soils of Kazakhstan.

2.2.2. Areal distribution of artificial radionuclides

Let us first say that not a single sample studied with γ-spectrometry revealed any other artificial radionuclides than ^{137}Cs or ^{241}Am; at that, determination thresholds for such radionuclides as ^{60}Co and ^{152}Eu were as low as 0.5 and 1.0 Bq/kg, respectively.

Contamination of the investigated lands with ^{137}Cs.

Total samples analyzed is 868, the results are shown in Annex 3. The studies plotted a map of the areal distribution of ^{137}Cs (Figure 6).

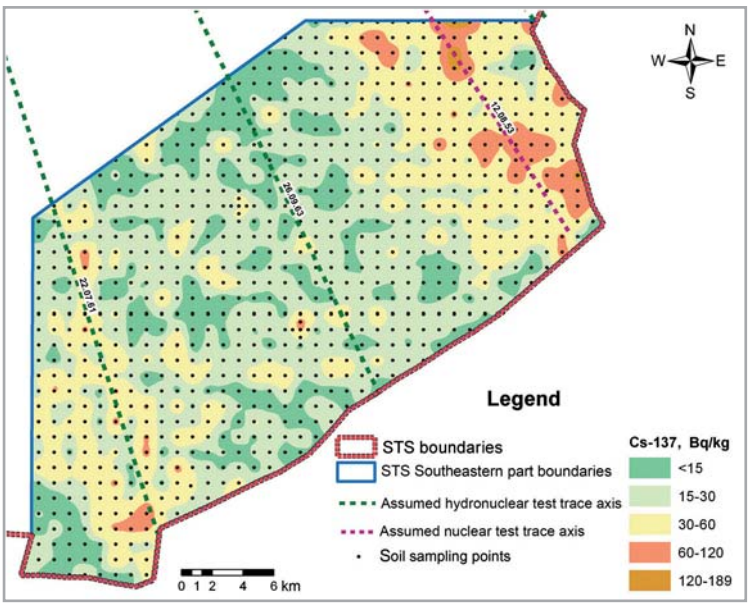


Figure 6. Distribution of ^{137}Cs in soils of southeastern STS

The specific activities range from <0.66 to 193 Bq/kg, with an average of 28 Bq/kg, upon that the bulk of the data is in the range of up to 80 Bq/kg, which is about 98 % of the total number of results. The histogram (Figure 7) of frequency distribution of the points with certain concentrations has a distribution close to lognormal one.

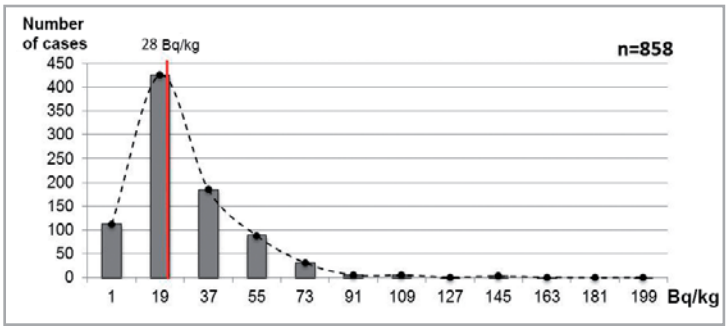


Figure 7. Specific activity distribution for ^{137}Cs in soils

The range of concentrations of key radionuclides from global fallout in the northern hemisphere, is presented in Table 6.

Table 6.

Range of concentrations of the main radionuclides due to global fallouts in northern hemisphere [8-15]

Radionuclide	^{137}Cs	^{90}Sr	$^{239+240}$Pu
Concentration, Bq/kg	4–30	1–19	0.02–5.0

In our case, the mean specific activity of ^{137}Cs in the area does not exceed the maximum global fallout background for this radionuclide, according to this table (30 Bq/kg). Higher specific activities of ^{137}Cs in soils are confined to radioactive fallout plumes from nuclear testing (Figure 6).

Contamination of the investigated lands with ^{241}Am.

According to studies a map of the areal distribution of 241Am (Figure 8).

The specific activity of this radionuclide ranges from <0.32 to 6.9 Bq/kg. Estimate of the average, for the area, concentration of ^{241}Am is a bit problematic, because in a large number of samples ^{241}Am concentration was less than the detection limit (minimum detectable activity) of the equipment and techniques used (about 55 % of all results). A complete elimination of these results would lead to a significant overestimation. Estimating the average concentration therefore, the ^{241}Am concentrations in such cases are to be equal to the detection limit. Also it is seen in the histogram for distribution of the radionuclide. Thus, a certain "average" concentration of ^{241}Am is actually an upper bound, and was 0.8 Bq/kg (Figure 9).

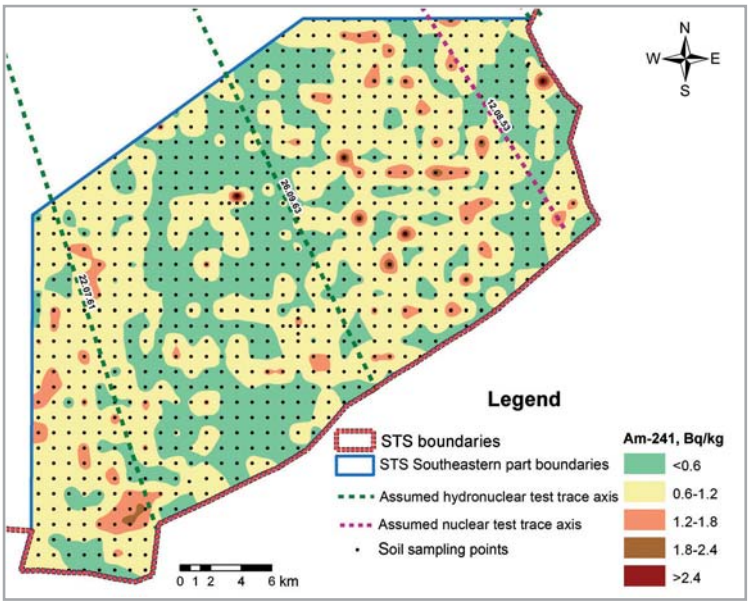


Figure 8. Distribution of ^{241}Am in soils of southeastern STS

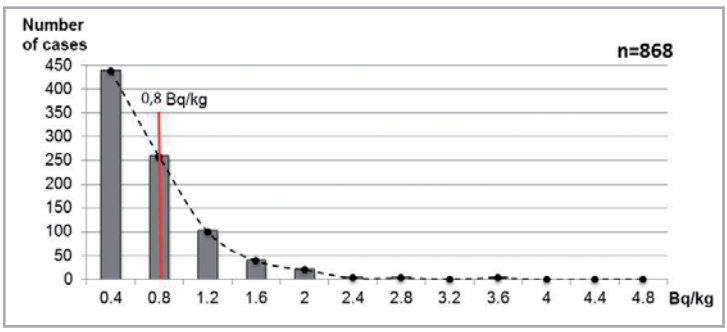


Figure 9. Specific activity distribution for ^{241}Am in soils

Contamination of the investigated lands with $^{239+240}$Pu.

Since a conventional method for determination of $^{239+240}$Pu – α-spectrometry with preliminary radiochemical extraction, is too laborious, in our studies aimed at evaluation of contamination pattern over the territory we were focused on revealing of correlation between ^{241}Am and plutonium. Such approach is quite widely accepted and reasonable particularly in cases with single source of contamination.

To determine the relationship $^{239+240}$Pu/^{241}Am the soil samples were prepared in a special way (preparation procedure involves several stages of attrition), the attrition quality was controlled by ^{241}Am content in aliquot samples. ^{241}Am concentration was determined as an average of three measurements of these samples.

The study results plotted relationship histograms for $^{239+240}Pu/^{241}Am$ (Figure 10). The average ratio $^{239+240}Pu/^{241}Am$ is 10.5 which is quite close to the expected theoretical value (total number of samples – 45).

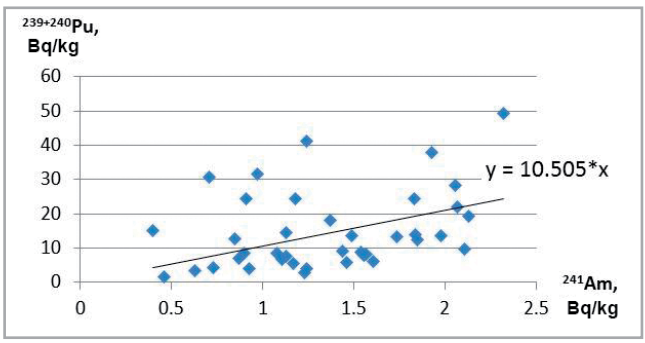


Figure 10. Ratio of $^{239+240}Pu$ concentration in soils to concentration of ^{241}Am

Thus, contamination with plutonium isotopes is consistent with americium contamination.The study results plotted a spotted distribution map for $^{239+240}Pu$ (Figure 11).

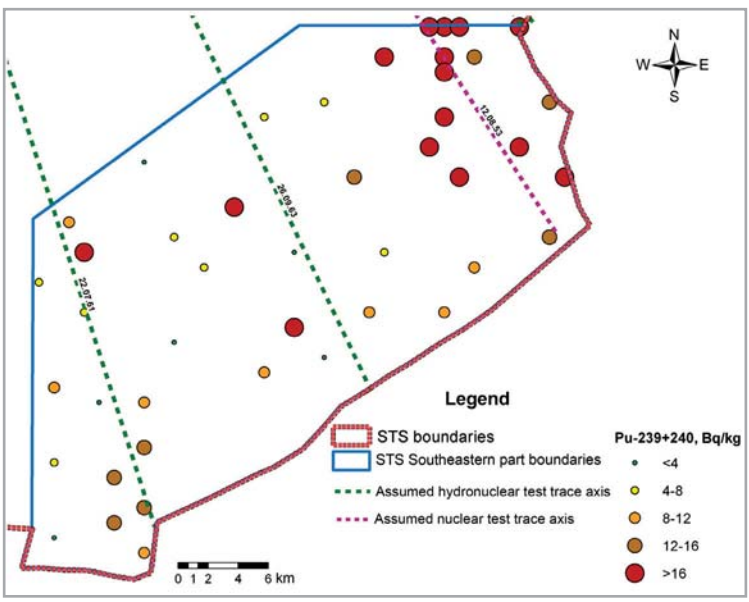


Figure 11. Concentration of $^{239+240}Pu$ in soils based on 2010-2011 investigations

Analysis of the results showed that, in determining ^{238}Pu, especially at low concentrations, there is an additive bias error, which causes an overestimation of the results by 0.35 Bq/kg, and most likely due to insufficient treatment of natural alpha-active isotopes. The ratio $^{238}Pu/^{239+40}Pu$ is shown in Figure 12.

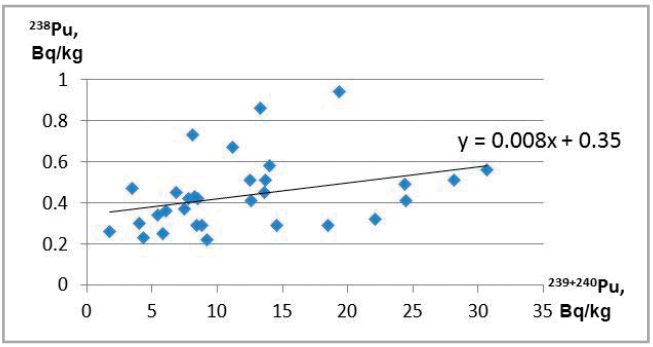


Figure 12. Ratio of ^{238}Pu concentration in soils to concentration of $^{239+240}$Pu

Thus, the average ratio of ^{238}Pu/$^{239+240}$Pu was 0.008, average concentration of ^{238}Pu – 0.07 Bq/kg, for calculation of dose loads, for convenience, value 0.1 Bq/kg was accepted. For ^{241}Pu a calculated ratio ^{241}Pu/$^{239+240}$Pu was accepted equal to 0.75.

Contamination of the investigated lands with ^{90}Sr

^{90}Sr was measured by two methods: first, the samples were analyzed by instrumental beta-spectrometric installation "Progress", for more detailed research a radiochemical extraction method was used.

The results of analyzes carried out by "Progress" are presented in Annex 3. The specific activities range from <100 to 1100 Bq/kg, based on the studies a spotted distribution map was built (Figure 13).

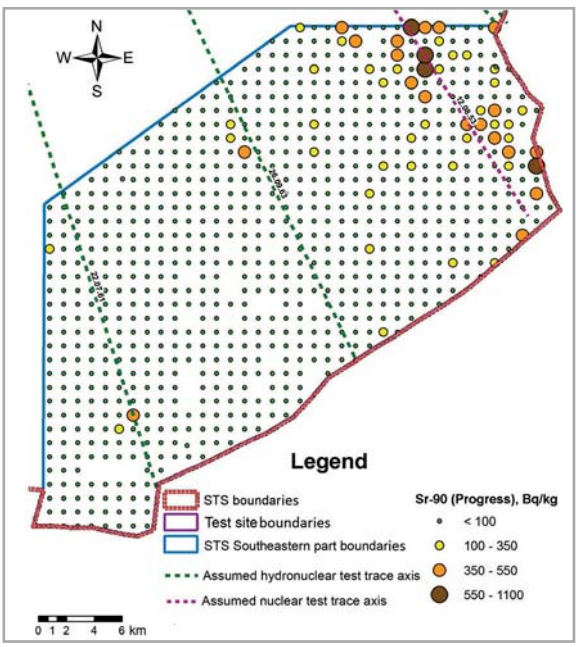


Figure 13. Distribution of ^{90}Sr in soils by "Progress"

This method has a higher detection limit compared to physical and chemical concentrating, which in turn are more costly and time consuming. Radiochemical separation method analyzed 45 samples for ^{90}Sr. The average concentration of ^{90}Sr was 21 Bq/kg. The studies plotted a spotted distribution map for ^{90}Sr (Figure 14). Maximal specific activities of ^{90}Sr were found at the plume of radioactive fallout from the first fusion explosion.

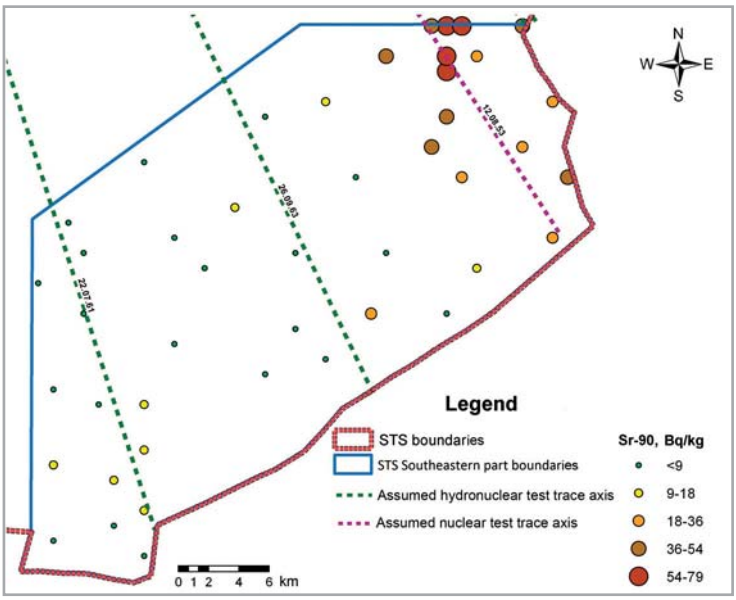


Figure 14. ^{90}Sr content in soils as determined in 2010-2011.

Contamination of the investigated lands with other radionuclides

Concentrations of other radionuclides such as ^{151}Sm, ^{99}Tc, which were not determined experimentally, but whose presence is expected, have been been determined by theoretical calculations based on the average concentrations of ^{137}Cs and the theoretical ratio of these isotopes. Calculations used the following averages – for ^{151}Sm – 2.2, ^{99}Tc – 0.4 Bq/kg.

An analysis of data on distribution of ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}$Pu in the study area distinguished several zones with different structure and levels of radioactive contamination generated by various sources (hydronuclear and thermonuclear tests).

2.2.3. Zonation of the lands based on areal distribution of radionuclides

Analysis of ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}$Pu radionuclides distribution over the studied area allow to identify several zones with different structure and level radioactive contamination due to different sources (hydronuclear and fusion tests). To identify areas with high specific activities of artificial radionuclides the authors selected the method, previously used in the analysis of the "northern" and "western" parts of the STS, for plotting the distribution of specific activities of ^{137}Cs and ^{241}Am along the profiles. The profile scheme is shown in Figure 15.

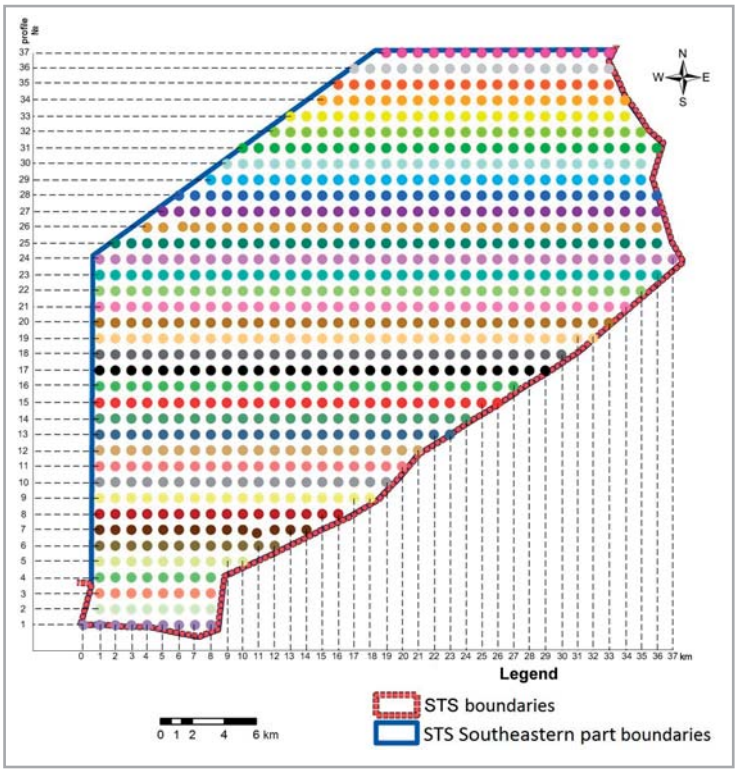
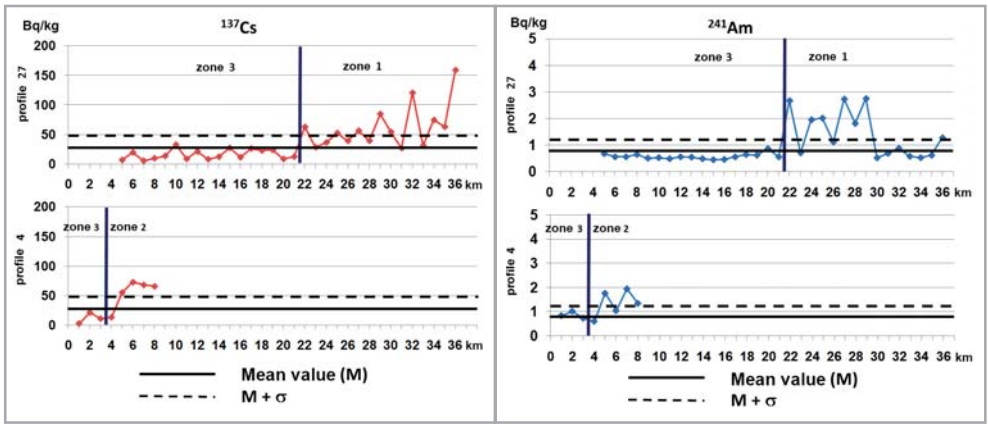


Figure 15. Location of profiles

Specific activity distribution curves (^{137}Cs and ^{241}Am) were plotted for each profile. Figure 16 shows two characteristic profiles for ^{137}Cs and ^{241}Am. The territory was divided into "background" (conditionally clean) zone and the zone with increased above average (for the whole territory) ^{137}Cs and ^{241}Am specific activity in soil. The following criterion has been accepted: the land is considered to be conditionally clean (background) if radionuclides specific activities do not exceed single standard deviation (δ) from the average value.

In distribution of ^{241}Am and ^{137}Cs two zones (1 and 2) may be distinguished, where higher specific activities in the soil cover were registered, and the zone with relatively low values. This pattern is clearly visible in the graphs for profiles 4 and 27 (Figure 16).

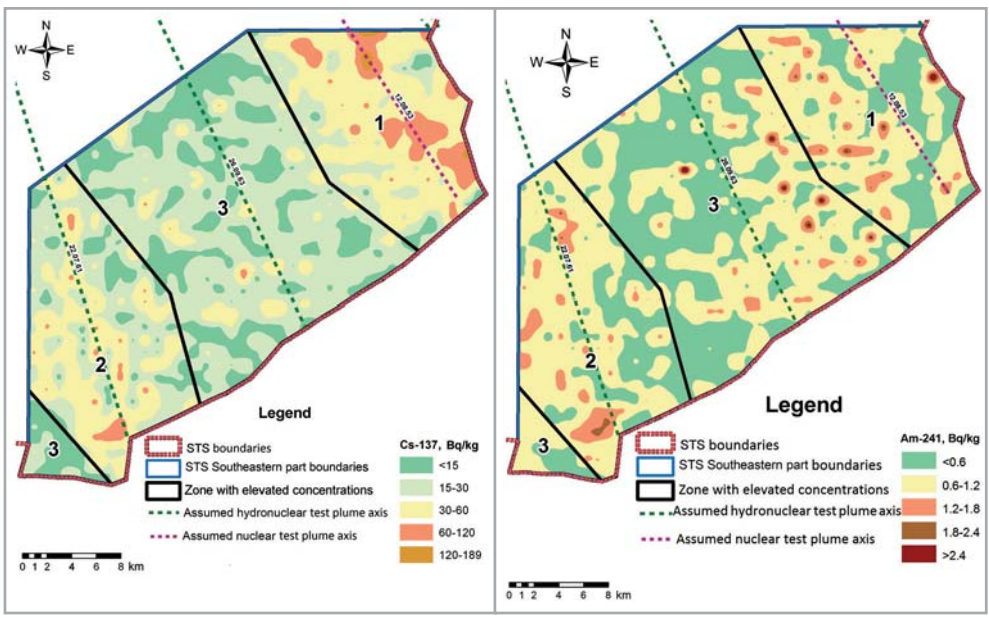
These zones have been distinguished based on the study of the areal distribution of artificial radionuclides. Also, when distinguishing the zones we took into account compliance of the areas with high specific activity of radionuclides with the areas where possibly radioactive clouds passed over.



a) b)

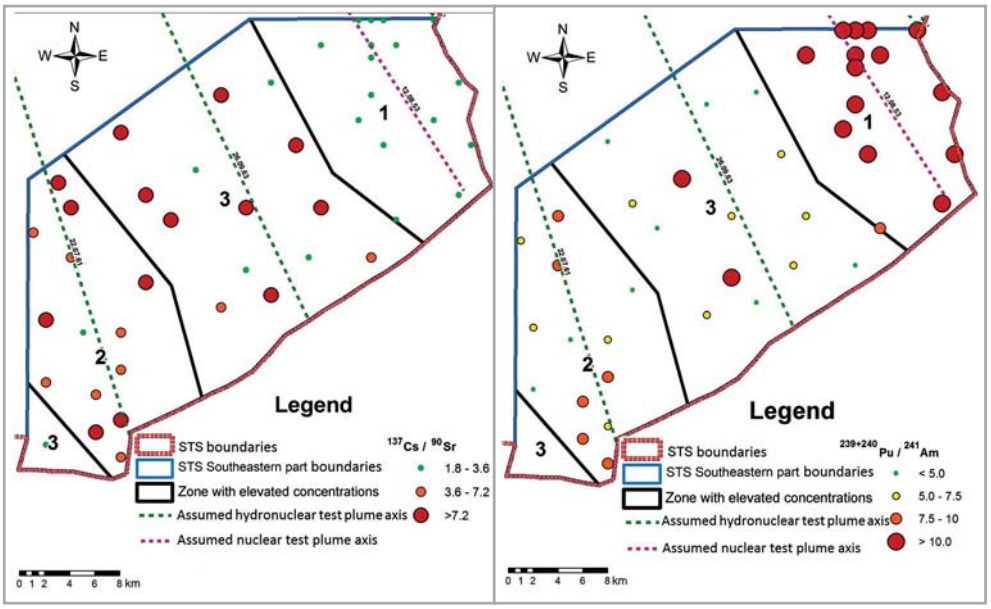
Figure 16. Diagram of concentrations of a) ^{137}Cs and b) ^{241}Am for 2 profiles

Location the zones and trails, presumably passing through a given area is shown on the map of ^{137}Cs and ^{241}Am distribution (Figure 17).



a) b)

Figure 17. Zones with high concentrations
of on the radionuclides distribution map for: a) ^{137}Cs, b) ^{241}Am



a) b)

Figure 18. Distribution of the specific activity ratios for a) ^{90}Sr and ^{137}Cs, б) $^{239+240}Pu$ and ^{241}Am

Average values of specific activity in each zone are use to assess the dose loads from the radionuclides. Since ^{137}Cs and ^{241}Am contents are determined in all solsamples, and those for ^{90}Sr and $^{239+240}Pu$ were determined in 45 samples only (~ 5 % of all soil samples), to determine the expected values of ^{90}Sr and $^{239+240}Pu$ for each zone we calculated the ratios of specific activity ^{137}Cs and ^{90}Sr, $^{239+240}Pu$ and ^{241}Am (Figure 18), ^{238}Pu and $^{239+240}Pu$ for each zone.

On the distribution maps for $^{90}Sr/^{137}Cs$ and $^{239+240}Pu/^{241}Am$ there is a portion corresponding to thermonuclear fallout from 12.08.53 (Zone 1). Within this area one can see increased contents of ^{90}Sr (compared to the model experiments) what makes the ratio $^{137}Cs/^{90}Sr$ close to 1.6 which characterizes global fallout due to, mainly, nuclear explosions worldwide.

Next were the graphs plotted for ratios of radionuclide specific activity for each zone and the calculated the ratios of radionuclides within the Zone 1 (Figure 19-21).

The resulting ratios of radionuclides were tabulated to calculate the average ^{90}Sr, $^{239+240}Pu$, ^{238}Pu from the known average specific activity of ^{137}Cs and ^{241}Am (Table 7).

Table 20.

Radionuclides ratios within the selected zones

Zone	$^{90}Sr/^{137}Cs$	$^{239+240}Pu/^{241}Am$	$^{238}Pu/^{239+240}Pu$
1	2.3	17.9	0.01
2	7.1	7	0.04
3	5.6	5.14	0.01

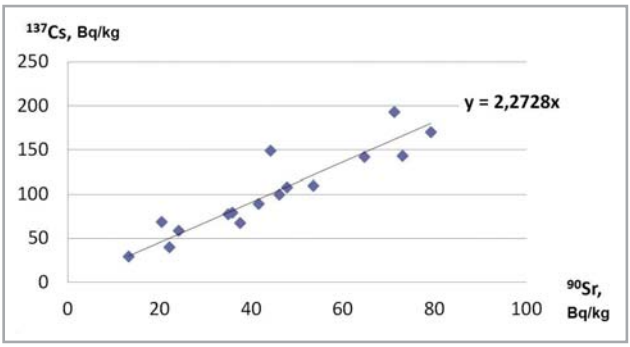


Figure 19. Specific activity ratio of ^{90}Sr and ^{137}Cs in Zone 1

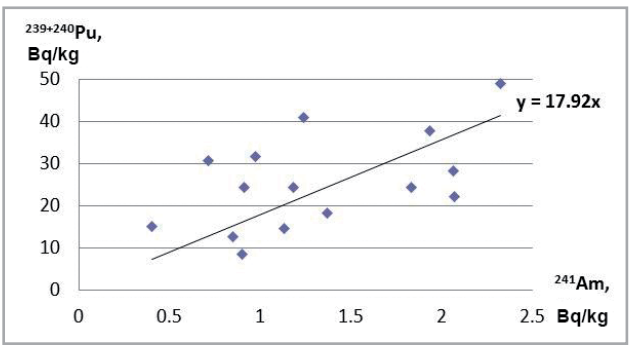


Figure 20. Specific activity ratio of $^{239+240}Pu$ and ^{241}Am in Zone 1

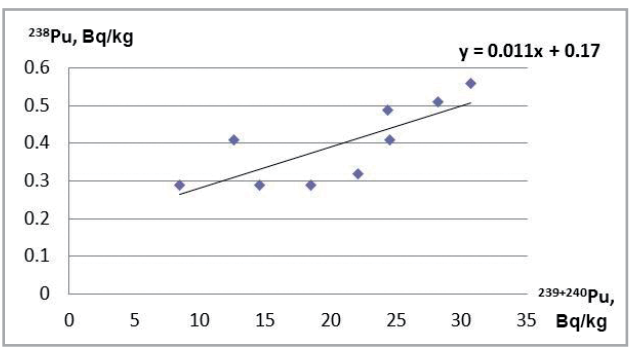


Figure 21. Specific activity ratio of ^{238}Pu and $^{239+240}Pu$ in Zone 1

Three zones were therefore identified at the surveyed area. Increased radionuclide concentrations in the zone 1 is stipulated by the plume of radioactive fallout after the fusion test 12.08.1953. In the zone 2, increased values for specific activity were also revealed; they were formed, most probably, by the plume of fallout from the hydronuclear test 22.07.1961. The zone 3 in the center of the territory has relatively low concentrations of the radionuclides. For singled out zones we calculated average specific activity of artificial radionuclides, which were used for further calculations of dose loads (Table 8).

Table 21.

Average specific activity of artificial radionuclides in the Zones, Bq/kg

^{137}Cs	^{90}Sr	^{241}Pu	^{238}Pu	^{241}Am	$^{239+240}$Pu	^{99}Tc	^{151}Sm
Zone 1							
43.9	18.9	0.6	0.1	0.8	14.9	0.7	3.5
Zone 2							
30.2	4.2	0.6	2.2	0.8	5.9	0.5	2.4
Zone 3							
19.0	3.4	0.5	0.04	0.7	3.7	0.3	1.5

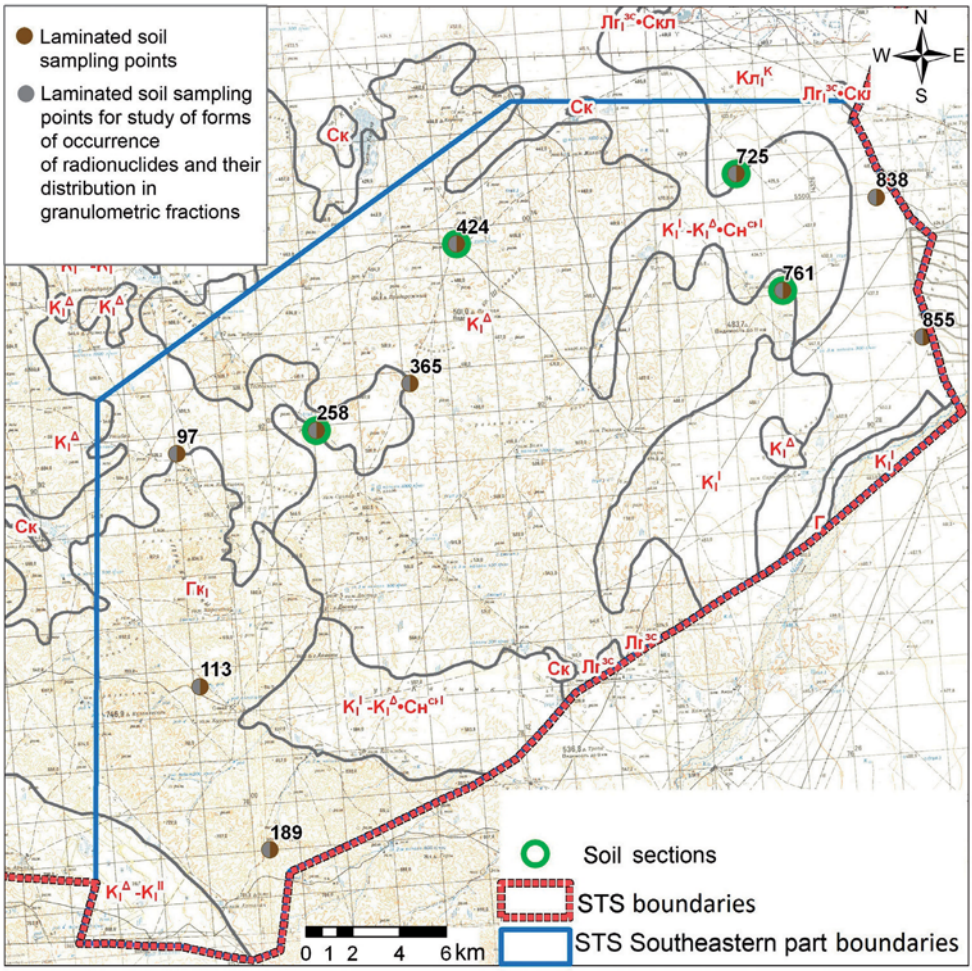
2.3. Radionuclide distribution in Soil

2.3.1. Distribution of artificial radionuclides within soil profile

To investigate the artificial radionuclides contamination of soils in the study area field studies were conducted where 10 research platforms were set; there soil was sampled layer-wise after 3 cm to the depth of 30 cm and 5 cm to the depth of 50 cm for determination of the main artificial radionuclides (Figure 22).

It should be noted that the sampling points for different types of analysis were selected based on the following parameters: maximal soil contamination with one or more artificial radionuclides, determination of them in various elements of the relief under different soil types or subtypes.

Distribution of ^{241}Am, ^{137}Cs and $^{239+240}$Pu in the soil profile shows that the highest concentrations are confined to the surface horizon with a few exceptions, when move into the underlying layer of 3-6 cm in the dry and loosely folded soil (Table 9). No well pronounced inversions in contents of these radionuclides in the profile depth can be identified.



Note: $Гк_I$ – mountain brown; $К_I$ – light-brown undeveloped;
$К_I^{II}$ – light brown moderately developed; $К_I^{III}$ – light brown gravelly undeveloped
Ск- Ordinary solonchak; Кл $^{сч.}$ – meadow solonchakous;
Лг- meadow salted; Кл^{к} meadow brown carbonaceous.

Figure 22. Schematic soil map of the study area with sampling points

Table 22.

Radionuclide content in the depth of the soil profile

Soil prof. №, soil type	Sampling depth, cm	Specific activity of radionuclides, Bq/kg			
		^{241}Am	^{137}Cs	$^{239+240}$Pu	^{90}Sr
725 Кл	0-3	< 0.37	44.4 ± 1.2	-	162.3 ± 8.4
	3-6	0.47 ± 0.27	33.8 ± 1.1	-	94.3 ± 6.9
	6-9	0.71 ± 0.29	49.0 ± 1.3	-	183.2 ± 7.2
	9-12	0.72 ± 0.28	28.0 ± 1.0	-	90.2 ± 6.1
	12-15	< 0.43	22.4 ± 0.9	-	57.3 ± 8.6
	15-18	0.45 ± 0.26	20.1 ± 0.9	-	76.9 ± 7.3
	18-21	< 0.40	0.79 ± 0.29	-	< 8.6
	21-24	0.56 ± 0.25	0.75 ± 0.28	-	< 7.4
	24-27	< 0.40	< 0.37	-	-
	27-30	< 0.52	0.86 ± 0.52	-	-
	30-35	0.70 ± 0.34	< 0.56	-	-
	35-40	< 0.50	< 0.49	-	-
	40-45	0.64 ± 0.34	< 0.74	-	-
	45-50	0.99 ± 0.36	< 0.50	-	-
761 $К_1$	0-3	2.73 ± 0.50	84.0 ± 2.5	16.22 ± 0.56	-
	3-6	1.12 ± 0.42	47.5 ± 1.9	12.65 ± 0.50	-
	6-9	< 0.60	< 0.62	0.41 ± 0.14	-
	9-12	< 0.50	< 0.62	< 0.25	-
	12-15	< 0.61	1.01 ± 0.57	< 0.20	-
	15-18	< 0.56	< 0.52	0.53 ± 0.18	-
	18-21	0.77 ± 0.38	< 0.83	0.25 ± 0.16	-
	21-24	0.42 ± 0.26	< 0.36	< 0.25	-
	24-27	0.56 ± 0.27	< 0.42	0.61 ± 0.17	-
	27-30	0.53 ± 0.27	0.80 ± 0.29	< 0.23	-
	30-35	< 0.39	0.70 ± 0.28	-	-
	35-40	< 0.43	< 0.47	-	-
	40-45	< 0.45	< 0.51	-	-
	45-50	< 0.48	< 0.47	-	-
838 $К_л$	0-3	1.06 ± 0.33	135.2 ± 2.0	30.0 ± 1.5	437 ± 11
	3-6	< 0.45	9.56 ± 0.64	1.87 ± 0.22	31.3 ± 7.2
	6-9	< 0.40	4.05 ± 0.45	2.09 ± 0.28	16.8 ± 6.4
	9-12	< 0.35	6.82 ± 0.52	1.55 ± 0.22	21.4 ± 3.8
	12-15	0.46 ± 0.26	2.76 ± 0.39	0.27 ± 0.16	< 8.1
	15-18	< 0.39	0.76 ± 0.30	0.25 ± 0.17	< 6.6
	18-21	0.78 ± 0.28	1.56 ± 0.34	0.57 ± 0.17	9.3 ± 3.4
	21-24	< 0.40	1.00 ± 0.31	-	< 12.4
	24-27	< 0.53	< 0.77	-	-
	27-30	< 0.56	< 0.75	-	-
	30-35	0.89 ± 0.27	< 0.45	-	-
	35-40	0.46 ± 0.25	< 0.30	-	-
	40-45	< 0.37	< 0.41	-	-
	45-50	< 0.35	< 0.38	-	-

Soil prof. №, soil type	Sampling depth, cm	Specific activity of radionuclides, Bq/kg			
		^{241}Am	^{137}Cs	$^{239+240}$Pu	^{90}Sr
855 $К_{л}^{к}$	0-3	< 0.76	104.4 ± 2.8	-	-
	3-6	0.90 ± 0.41	7.48 ± 0.94	-	-
	6-9	1.20 ± 0.41	< 0.64	-	-
	9-12	< 0.67	1.55 ± 0.66	-	-
	12-15	0.85 ± 0.39	3.00 ± 0.75	-	-
	15-18	< 0.56	< 0.60	-	-
	18-21	< 0.56	< 0.78	-	-
	21-24	1.07 ± 0.41	< 0.63	-	-
	24-27	0.74 ± 0.40	< 0.66	-	-
	27-30	< 0.39	< 0.39	-	-
	30-35	< 0.39	0.46 ± 0.26	-	-
	35-40	0.47 ± 0.25	< 0.35	-	-
	40-45	0.67 ± 0.26	< 0.44	-	-
	45-50	< 0.36	0.63 ± 0.28	-	-
424 $К_{1}$ deep effervescent.	0-3	1.39 ± 0.29	78.5 ± 1.8	5.15 ± 0.38	17.6 ± 4.4
	3-6	2.27 ± 0.33	59.74 ± 1.47	12.03 ± 0.72	11.4 ± 3.7
	6-9	< 0.42	5.48 ± 0.52	-	< 6.6
	9-12	< 0.38	3.04 ± 0.42	-	11.6 ± 4.4
	12-15	< 0.41	1.24 ± 0.34	-	< 7.1
	15-18	< 0.36	1.18 ± 0.33	-	< 7.0
	18-21	< 0.56	< 0.89	-	-
	21-24	< 0.51	< 0.89	-	-
	24-27	< 0.45	< 0.76	-	-
	27-30	< 0.49	< 0.77	-	-
	30-35	< 0.39	< 0.39	-	-
	35-40	< 0.33	< 0.40	-	-
	40-45	< 0.40	< 0.32	-	-
	45-50	0.99 ± 0.34	< 0.67	-	-
365 $К_{1}^{щ}$	0-3	0.82 ± 0.40	10.21 ± 0.95	-	-
	3-6	< 0.58	1.30 ± 0.61	-	-
	6-9	< 0.55	< 0.90	-	-
	9-12	< 0.64	< 0.89	-	-
	12-15	0.88 ± 0.40	< 0.79	-	-
	15-18	< 0.45	0.60 ± 0.29	-	-
	18-21	< 0.44	0.58 ± 0.30	-	-
	21-24	< 0.45	0.89 ± 0.31	-	-
	24-27	< 0.43	< 0.39	-	-
	27-30	< 0.41	0.63 ± 0.29	-	-
	30-35	0.75 ± 0.31	< 0.41	-	-
	35-40	0.60 ± 0.29	1.49 ± 0.37	-	-
	40-45	< 0.41	< 0.45	-	-
	45-50	< 0.45	1.18 ± 0.31	-	-

Soil prof. №, soil type	Sampling depth, cm	Specific activity of radionuclides, Bq/kg			
		^{241}Am	^{137}Cs	$^{239+240}$Pu	^{90}Sr
258 $К_1$ poorly developed.	0-3	0.84 ± 0.29	37.10 ± 1.13	-	-
	3-6	0.69 ± 0.29	5.71 ± 0.51	-	-
	6-9	0.78 ± 0.40	< 0.68	-	-
	9-12	< 0.65	< 0.83	-	-
	12-15	< 0.57	< 0.81	-	-
	15-18	0.89 ± 0.40	< 0.53	-	-
	18-21	0.71 ± 0.40	< 0.63	-	-
	21-24	0.71 ± 0.41	< 0.74	-	-
	24-27	0.86 ± 0.42	< 0.89	-	-
	27-30	< 0.48	0.77 ± 0.29	-	-
	30-35	< 0.43	< 0.42	-	-
	35-40	< 0.46	0.43 ± 0.26	-	-
	40-45	< 0.57	< 0.45	-	-
	45-50	1.14 ± 0.54	< 0.73	-	-
97 Кл ^{сч}	0-3	1.51 ± 0.39	51.8 ± 1.9	12.97 ± 0.58	-
	3-6	0.64 ± 0.34	40.5 ± 1.7	-	-
	6-9	< 0.54	7.00 ± 0.88	-	-
	9-12	< 0.55	5.59 ± 0.79	-	-
	12-15	0.73 ± 0.35	1.09 ± 0.59	-	-
	15-18	< 0.45	< 0.85	-	-
	18-21	< 0.56	< 0.77	-	-
	21-24	0.49 ± 0.23	0.88 ± 0.26	-	-
	24-27	< 0.39	0.50 ± 0.25	-	-
	27-30	< 0.34	< 0.37	-	-
	30-35	< 0.35	< 0.36	-	-
	35-40	< 0.32	0.37 ± 0.22	-	-
113 $Гк_1$	0-3	0.58 ± 0.26	26.57 ± 0.99	-	-
	3-6	< 0.38	3.09 ± 0.41	-	-
	6-9	< 0.39	1.17 ± 0.31	-	-
	9-12	< 0.36	0.70 ± 0.28	-	-
	12-15	< 0.39	< 0.32	-	-
	15-18	< 0.32	< 0.36	-	-
	18-21	< 0.49	< 0.77	-	-
	21-24	< 0.50	< 0.57	-	-
	24-27	0.59 ± 0.34	< 0.79	-	-
	27-30	0.99 ± 0.34	< 0.80	-	-
189 $Гк_1$	0-3	0.76 ± 0.38	49.6 ± 1.9	-	19.7 ± 7.7
	3-6	< 0.51	8.85 ± 0.94	-	18.0 ± 6.3
	6-9	0.69 ± 0.35	4.14 ± 0.75	-	< 7.3
	9-12	< 0.51	2.68 ± 0.68	-	< 10.5
	12-15	< 0.37	7.22 ± 0.55	-	< 13.5
	15-18	< 0.55	< 0.83	-	-
	18-21	< 0.36	< 0.40	-	-
	21-24	< 0.47	< 0.75	-	-
	24-27	< 0.30	0.46 ± 0.23	-	-
	27-30	< 0.29	< 0.38	-	-

Note: Кл-meadow-brown; $К_1$ – light brown: Кл^к meadow brown carbonaceous;
$К_1$ deep effervescent. - light-brown deep effervescent; $К_1^{щ}$– light brown gravelly undeveloped;
$К_1$ undeveloped. – light-brown undeveloped; Кл $^{сч.}$ – meadow brown solonchakous;
$Гк_1$ – mountain brown.

Thus, as the data in the table show, regardless of the type or subtype of soil, topography and, consequently, their texture (all tested soils are loamy soil) that main contents of ^{241}Am, ^{137}Cs and $^{239+240}$Pu are in the first surface layer. Maximal ^{90}Sr in the soil profile is also confined to the surface layer, but in the depth distribution there is not always a steady decline of values, there are abrupt changes, which is typical for this radionuclide, the most soluble and mobile. This process is enhanced in these conditions – conditions of drainage of the upper soil horizons, as evidenced by the lack of carbonates in them.

2.3.2. Speciation of artificial radionuclides in soils

10 research platforms were set in areas with the highest levels of contamination and characterized by different soil types. Layout of sampling points is shown in Figure 19.

At selected points samples were taken to a depth of 0-3 cm from 600 cm^2 area. Upon preliminary preparation of soil sample, exchange, organic, mobile and bind forms subsamples which characterise easily accessible, potentially accessible and non-accessible for the plants forms. 1M-acetated-ammoniacal buffer was used (widely used in the practice of sequential fractionation) as an extractive agent of exchangeable species. Organic species was isolated by soil treatment with solution 0.1n NaOH, mobile species – 1 MHCl. The ratio of soil and leaching solution at all stages of the experiment remained 1:5. The well-bound species was determined directly in the remains of the soil after leaching. ^{137}Cs and ^{241}Am in soil samples and extracts were determined by instrumental gamma-spectrometric method. Radionuclide $^{239+240}$Pu was determined by radiochemical method with α-spectrometry. ^{90}Sr was determined by radiochemical method.

Distribution of ^{241}Am speciation is presented in Table 10.

Data are expressed in the specific activity values of radionuclide converted to 1 kg of soil, and a percentage of the total content of all species.

Table 10.

^{241}Am speciation Bq/kg, % of the total contents of all species

Zone	Point №	Exchangeable species (1M CH_3COONH_4)		Organic species (0.1н NaOH)		Mobile species (1M HCl)		Well-bounded species	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	725	1.8	46.0	< 1.9	0.0	1.7	43.5	0.4	10.5
	761	< 1.2	0.0	< 1.2	0.0	3.4	100	< 0.4	0.0
	838	1.4	14.6	< 1.1	0.0	7.0	72.8	1.2	12.6
	855	1.4	18.3	< 1.2	0.0	5.1	66.7	1.2	15.0
average, Zone 1			19.7		-		70.7		**9.5**
Zone 2	97	< 1.2	0.0	< 1.2	0.0	2.8	82.1	0.6	18.9
	113	< 1.2	0.0	< 1.2	0.0	2.8	74.5	0.9	25.3
	189	< 1.2	0.0	1.5	27.4	3.1	56.6	0.9	16.1
average, Zone 2			-		9.1		71.1		**19.8**
Zone 3	424	< 1.0	0.0	< 0.8	0.0	< 3.6	0.0	4.2	100.0
	365	< 1.2	0.0	< 1.9	0.0	< 1.3	0.0	1.1	100.0
	258	< 1.2	0.0	< 0.8	0.0	4.6	86.8	0.7	13.2
Average, Zone 3			-		-		28.9		71.1

Note: *- estimated data
In the calculations of the relative content of radionuclide ^{241}Am the specific activities less than the limit of detection methods was taken "0".

During determination ^{241}Am in soil extracts in most cases, values less than the detection limits were obtained, in particular, for exchangeable and organic species. In connection, in the calculation of the ratios of ^{241}Am species the values less than the detection limit were taken as "0", and the results of the relative content of the radionuclide speciation should be viewed as estimates. To obtain more accurate data there is a need for more research in relation to the "background" areas.

The results show that there is a difference in the ratio of ^{241}Am speciation in soils of different zones of the studied area. Analyzing the data obtained for zone 1 and zone 2, a commont feature should be noted – the mobile species is dominant for all the considered samples. It is estimated that the fraction of the mobile species has about 43 to 82 % of the total content of all ^{241}Am species. One should keep in mind here that a value less than the detection limit for specific activity of the radionuclide in organic species are almost flush with the quantitative data on the radionuclide content in the exchangeable and well-bound species. Predominant content of mobile species of ^{241}Am in soil of zone 1 and 2 is no doubt.

In contrast to zone 1 and 2 zones, in soils of 3rd zone it is hard to identify the prevalence of various species of radionuclide because data differ.

Below is distribution of ^{137}Cs species (Table 11).

Table 11.

^{137}Cs speciation Bq/kg, % of the total contents of all species

Zone	Point №	Exchangeable species (1M CH_3COONH_4)		Organic species (0.1н NaOH)		Mobile species (1M HCl)		Well-bounded species	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	725	2.2	5.1	< 1.2	2.7	< 3.4	7.7	37.1	84.5
	761	6.5	6.7	< 2.9	2.9	< 4	4.1	83.8	86.2
	838	5.8	3.2	2.6	1.5	7.6	4.3	162.3	91.0
	855	30.4	14.1	3.2	1.5	4.9	2.3	176.5	82.1
average, Zone 1			7.3		0.7		1.6		**90.1**
Zone 2	97	< 3.8	11.3	< 3.0	8.9	3.2	9.5	23.6	70.2
	113	17.6	16.9	< 2.8	2.7	14.1	13.5	69.7	66.9
	189	6.6	11.9	< 1.0	1.8	4.9	8.9	42.8	77.4
average, Zone 2			13.4		-		11.6		**78.5**
Zone 3	424	24.2	18.2	5.4	4.1	13.6	10.2	89.7	67.5
	365	3.9	11.9	< 1.2	3.7	3.8	11.6	23.7	72.7
	258	24.6	24.4	< 1.2	1.2	12.1	12.0	62.7	62.3
average, Zone 3			18.2		1.4		11.5		68.7

Note: *- estimated data.
In the calculations of the relative content of radionuclide ^{137}Cs the specific activities less than the limit of detection methods was taken "0".

According to data on specific activity and relative content of ^{137}Cs species it should be noted that most of the radionuclide accounts for well-bound species in all zones. This indicates that in the soil of zone 1 the relative content of well-bound species is significantly higher (90 %, on average) than in soil of zone 2 and 3 (68.7 – 78.5 %).

In general, behavior of ^{137}Cs in the soil of study area is similar to the previously studied soils ща "background" ("Northern" and "Western") areas, where at least 68 – 70% accounts for well-bound species of ^{137}Cs.

Table 12 presents the ratios of ^{90}Sr speciation.

Table 12.

^{90}Sr speciation Bq/kg, % of the total contents of all species

Zone	Point №	Exchangeable species (1M CH_3COONH_4)		Organic species (0.1н NaOH)		Mobile species (1M HCl)		Well-bounded species	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	725	34.3	17.8	< 3	1.5	24.8	12.8	131.1	67.9
	761	45.4	15.4	4.8	1.6	40.9	13.9	203.7	69.1
	838	43.8	6.6	< 2.9	0.4	38.4	5.8	582.0	87.2
	855	59.7	5.9	355.3	35.0	49.4	4.9	552.0	54.3
average, Zone 1			11.4		9.6		9.3		**69.6**
Zone 2	97	16.4	47.7	< 2.3	6.7	7.7	22.4	< 8.0	23.3
	113	49.0	48.9	< 2.3	2.3	31.9	31.9	16.9	16.9
	189	42.5	56.1	< 2.7	3.6	23.0	30.3	< 7.6	10.0
average, Zone 2			50.9		3.9		34.5		**15.9**
Zone 3	424	38.8	43.4	3.9	4.4	36.0	40.3	10.7	12.0
	365	22.8	41.8	< 2.3	4.2	15.0	27.5	< 14.4	26.4
	258	45.4	51.8	< 2.7	3.1	31.4	35.8	< 8.2	9.4
average, Zone 3			45.7		4.2		28.2		16.7

Note: *- estimated data.
In the calculations of the relative content of radionuclide ^{137}Cs the specific activities less than the limit of detection methods was taken "0".

In the calculations of the relative content of ^{90}Sr species, the specific activities less than the detection limit of the method used, obtained, in particular, in organic and well-bound species have been accepted by us as numerical values. Since, these limits have significant high levels, reaching in some cases, "<8.2" or "<14.2" (in well-bound species) and are not allowed to neglect them.

The study of ^{90}Sr species in soils of the studied ecosystem discovers new features and differences in radionuclide contamination of soils in the studied zones.

So, for Zone 1 the distinctive is prevalence of radionuclide well-bound species. The variation of the relative values of the well-bound species ranges from 54.3 to 87.2%, accounting for an average of 69.6%. The less significant by content of ^{90}Sr is exchangeable species (11.4%), followed in descending order – mobile (9.3%) and organic species. A similar distribution of ^{90}Sr is observed in soils of "Experimental field" site [16].

In soils of 2nd and 3rd zones the dominant species of ^{90}Sr is exchangeable, accounting for an average of 45.7 and 50.9%, respectively. The second important by ^{90}Sr content is mobile species (28.0 and 34.5%, respectively). The well-bound and organic species species are the smallest for ^{90}Sr (16.3). This type of distribution is characteristic for ^{90}Sr in soils of previously studied "background" areas of the STS ("North" and "Western") [17, 18].

The study of the ^{90}Sr speciation in soils of the study area once again confirm the different nature of contamination in all three zones previously identified by levels of areal radionuclide contamination.

Study results on the $^{239+240}Pu$ speciation are shown in Table 13. The results are presented for 6 out of 10 samples invetigated, for 4 out of 10 samples the results have not been obtained due to the low yield of $^{239+240}Pu$ in the radiochemical extraction.

Table 13.

$^{239+240}Pu$ speciation Bq/kg, % of the total contents of all species

Zone	Point №	Exchangeable species (1M CH_3COONH_4)		Organic species (0.1н NaOH)		Mobile species (1M HCl)		Well-bounded species	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	725	2.4	12.1	2.7	13.6	3.7	18.6	11.1	55.7
	761	1.4	6.3	1.3	5.8	1.8	8.1	17.8	79.8
	838	0.8	1.7	0.8	1.7	1.4	9.0	42.9	93.5
	855	0.5	1.3	1.0	2.5	1.1	2.8	36.7	93.4
range		0.5 – 2.4	1.3 – 12.1	0.8 – 2.7	1.7 – 13.6	1.1 – 3.7	2.85 – 18.6	11.1 – 42.9	55.7 – 93.5
average		1.3	**5.3**	1.4	**5.9**	2.0	**8.1**	27.1	**80.6**
Note: *- estimated data									

The main content of $^{239+240}Pu$ in soil samples, taken from zone 1, accounts for well-bound species, on average, 80.6 % of the total content of all species. And the variation of the values of the relative content of well-bound species ranges from 55.7 to 93.5 %. Less significant by $^{239+240}Pu$ content is mobile species (8.1 %), followed in descending order – organic (5.9 %) and exchangeable (5.3 %) species.

In general, the behavior of $^{239+240}Pu$ in soils of the study area does not differ from that in soils of the previously studied STS areas.

2.3.3. Distribution of radionuclides in soil granulometric fractions

The study of the radionuclide distribution in soil granulometric fractions allows evaluating the contribution of soil to air pollution at the re-suspension of dust and predicting local secondary redistribution of radionuclides by horizontal migration due to wind erosion. 100 micron fine dust particles play a key role in assessing the getting of radionuclides into the atmosphere from the surface of the soil [19].

To study the distribution of radionuclides 10 spot samples were taken to a depth of 0-3 cm. Location scheme of sampling points is shown in Figure 11. Sampling was carried out in areas with the highest levels of radioactive contamination with studied radionuclides, and characterized by different types of soils.

We studied the distribution of ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+241}Pu$ in soil fractions with dimensions 1000-500, 500-250, 250-100, 100-63, 63-40 and <40 microns, isolated by "wet sieving" in the flow of water. In the separated fractions of soil, after drying to air-dry state and weighting, the contents of these radionuclides were determined. ^{137}Cs and ^{241}Am in the samples were determined by gamma-spectrometry, $^{239+241}Pu$ – α-spectrometric method with preliminary radiochemical extraction, ^{90}Sr by radiochemical method.

It was found that in soils of the study area in the upper 0-3 cm soil layer, taking an average of 28 % of the total weight, the large fractions with dimensions 1,000-500 microns dominate. Contribution of fractions 500-250, 250-100, 100-63 and 63-40 microns in the total weight of the soil is, on average, 17, 15, 15 and 11 %, respectively. The most fine fraction (<40 mm) of the soil surface horizon, the mostly involved in the wind transport, is 14 %.

Table 14, Table 15, Table 16 and Table 17 show the data on distribution of ^{241}Am and ^{137}Cs, ^{90}Sr and $^{239+241}$Pu in granulometric fractions.

Table 14.

Distribution of ^{241}Am in granulometric fractions of the surface soil layer (0-3 cm), Bq/kg, %

Zone	Point №	1,000–500 micron (28 %)		500–250 micron (17 %)		250–100 micron (15 %)		100–63 micron (15 %)		63–40 micron (11 %)		< 40 micron (14 %)	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	761	0.45	4.2	1.10	10.4	0.48	4.5	2.77	26.1	1.64	15.4	4.18	39.4
	725	0.3	7.1	0.59	13.9	0.36	8.5	1.47	34.6	0.71	16.7	0.82	19.3
	838	< 0.33	2.9	2.30	19.9	1.51	13.1	1.51	13.1	1.79	15.5	4.1	35.7
	855	0.77	6.9	3.8	33.6	1.9	17.8	2.4	21.1	1.6	14.0	0.8	6.7
average, Zone 1			5.3		19.4		11.0		23.7		15.4		**25.3**
2 Zone	97	< 0.29	5.4	0.9	18.0	1.6	29.3	1.4	26.7	0.7	13.5	< 0.39	7.2
	113	0.85	7.9	1.2	11.3	2.0	19.0	2.7	25.4	1.8	16.6	2.1	19.8
	189	0.55	10.6	0.6	12.0	0.9	16.6	1.3	24.5	0.9	18.5	0.9	17.8
average, Zone 2			8.0		13.7		21.6		25.5		16.2		**14.9**
Zone 3	424	1.56	9.5	3.39	20.7	1.56	9.5	3.69	22.6	2.56	15.7	3.6	22.0
	365	< 0.32	10.0	0.41	12.8	0.32	10.0	0.55	17.1	0.84	26.2	0.8	24.0
	258	0.89	12.6	0.74	10.5	1.7	24.0	1.5	21.0	1.6	22.6	0.7	9.3
average, Zone 3			10.7		14.7		14.5		20.2		21.5		18.4

Table 15.

Distribution of ^{137}Cs in granulometric fractions of the surface soil layer (0-3 cm), Bq/kg, %

Zone	Point №	1,000–500 micron (28 %)		500–250 micron (17 %)		250–100 micron (15 %)		100–63 micron (15 %)		63–40 micron (11 %)		< 40 micron (14 %)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
Zone 1	761	38.9	6.8	228.70	39.8	113.5	19.7	61	10.6	55.9	9.7	76.8	13.4
	725	24.9	9.6	97.00	37.5	45.1	17.4	28.3	10.9	29.5	11.4	33.7	13.0
	838	65.1	8.1	404.9	50.3	113.5	14.1	81.9	10.2	61.7	7.7	77.8	9.7
	855	73.7	5.0	787.6	54.0	374.2	25.6	77.4	5.3	70.8	4.8	76.1	5.2
average, 1 Zone			7.4		45.4		19.2		9.3		8.4		**10.3**
Zone 2	97	15.2	9.5	16.2	10.1	21.3	13.3	34.7	21.6	36.7	22.9	36.2	22.6
	113	63	12.6	78	15.5	81	16.1	87.7	17.5	83.1	16.6	109	21.7
	189	31.3	11.8	33.5	12.6	41.2	15.5	49.4	18.6	47.1	17.7	63.5	23.9

Zone	Point №	1,000–500 micron (28 %)		500–250 micron (17 %)		250–100 micron (15 %)		100–63 micron (15 %)		63–40 micron (11 %)		< 40 micron (14 %)	
		Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
average, Zone 2			11.3		12.7		15.0		19.2		19.1		**22.7**
Zone 3	424	83.2	12.7	98.4	15.0	92.3	14.1	122.4	18.7	121.1	18.5	138.8	21.2
	365	10.01	7.6	15.3	11.6	14.8	11.2	29.3	22.1	27.3	20.6	35.6	26.9
	258	38.3	9.8	57.7	14.8	72	18.4	85.3	21.8	66.4	17.0	71.4	18.3
average, Zone 3			10.0		13.8		14.6		20.9		18.7		22.1

Table 16.

Distribution of ^{90}Sr in granulometric fractions of the surface soil layer (0-3 cm), Bq/kg, %

Zone	Point №	1,000–500 micron (28 %)		500–250 micron (17 %)		250–100 micron (15 %)		100–63 micron (15 %)		63–40 micron (11 %)		< 40 micron (14 %)	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	761	128.1	8.0	934.0	58.7	317	19.9	70.6	4.4	68.8	4.3	73	4.6
	725	98.3	14.8	336.0	50.5	123.7	18.6	41.9	6.3	30.8	4.6	34.7	5.2
	838	203.0	8.0	1792.0	70.4	247	9.7	136.2	5.4	76.9	3.0	88.8	3.5
	855	147.6	2.8	3433.0	64.6	1489.0	28.0	96.1	1.8	89.8	1.7	61.2	1.2
average, Zone 1			8.4		61.0		19.1		4.5		3.4		**3.6**
Zone 2	97	< 7.6	11.9	<11.2	17.5	< 9.7	15.1	11.5	17.9	14.2	22.2	< 9.9	15.4
	113	30.5	18.8	22.1	13.6	29.6	18.2	36.5	21.9	29.6	18.2	15.2	9.3
	189	< 7.6	10.3	< 8.9	12.0	15.7	21.2	17.5	23.6	< 8.9	12.0	15.5	20.9
average, Zone 2			13.6		14.4		18.2		21.2		17.5		**15.2**
Zone 3	424	21.9	21.3	16.4	15.9	23.6	22.9	15.9	15.4	16.8	16.3	< 8.4	8.2
	365	<15.5	17.7	<15.8	18.0	12.3	14.0	21.4	24.4	< 12.4	14.1	< 10.4	11.8
	258	<11.0	13.8	< 9.1	11.4	< 9.6	12.0	24.5	30.6	12.9	16.1	12.9	16.1
average, Zone 3			17.6		15.1		16.3		23.5		15.5		12.0

Table 17.

Distribution of $^{239+240}$Pu in granulometric fractions of the surface soil layer (0-3 cm), Bq/kg, %

Zone	Point №	1,000–500 micron (28 %)		500–250 micron (17 %)		250–100 micron (15 %)		100–63 micron (15 %)		63–40 micron (11 %)		< 40 micron (14 %)	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
Zone 1	761	6.11	4.5	49.90	37.0	22.59	16.7	12.93	9.6	18.71	13.9	24.73	18.3
	725	4.85	6.9	21.21	30.3	10.61	15.1	17.25	24.6	7.86	11.2	8.26	11.8
	838	11.62	5.9	90.30	45.9	22.25	11.3	26.78	13.6	14.43	7.3	31.2	15.9
	855	14.4	4.5	183.3	56.9	84.8	26.3	17.2	5.4	12.8	4.0	9.5	2.9

Zone	Point №	1,000–500 micron (28 %)		500–250 micron (17 %)		250–100 micron (15 %)		100–63 micron (15 %)		63–40 micron (11 %)		< 40 micron (14 %)	
		Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
average, Zone 1			5.5		42.5		17.4		13.3		9.1		**12.2**
Zone 2	97	1.9	4.5	4.3	9.9	8.7	20.0	15.3	35.4	5.1	11.8	7.9	18.4
	113	5.2	-	13.3	-	17.1	-	25.7	-	date none	-	8.9	-
	189	2.1	5.5	5.2	13.7	5.4	14.0	15.2	39.6	4.9	13.0	5.4	14.2
average, Zone 2			5.0		11.8		17.0		37.5		12.4		**16.3**
Zone 3	424	5.06	6.0	8.48	10.1	8.63	10.3	38.10	45.3	8.62	10.2	15.3	18.1
	365	0.47	4.7	1.05	10.5	1.80	18.0	2.08	20.8	1.83	18.3	2.8	27.8
	258	2.35	8.4	3.39	12.2	4.2	14.9	4.8	17.1	5.4	19.3	7.8	28.1
average, Zone 3			6.4		10.9		14.4		27.7		5.9		24.7

For a clearer presentation, the results of the radionuclide distribution in granulometric fractions are presented as a normalized histogram with relative contribution of each fraction in the total amount of each of the studied radionuclide (Figure 23).

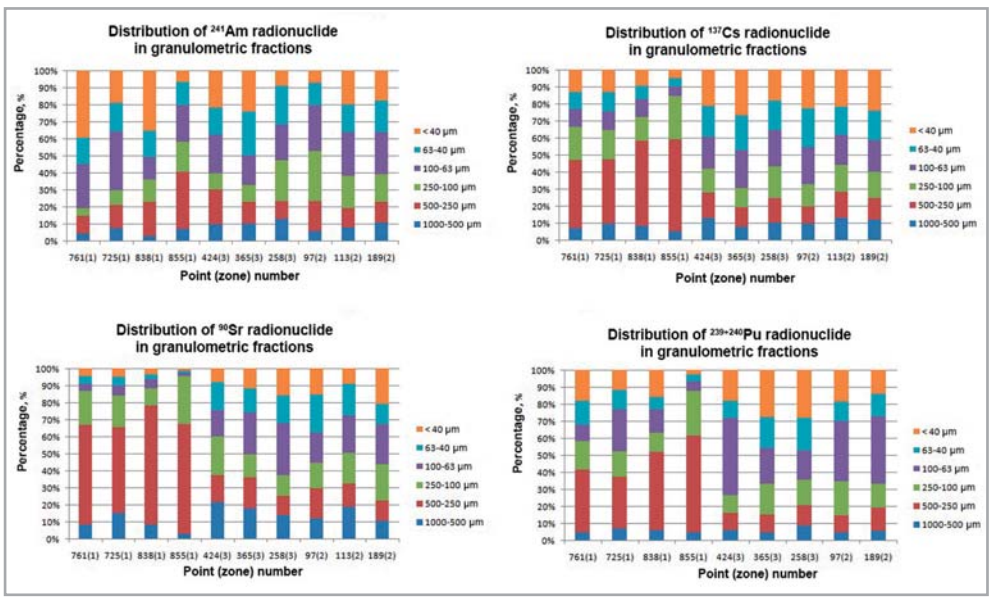


Figure 23. Histograms of the normalized distribution of ^{241}Am and ^{137}Cs, ^{90}Sr and $^{239+241}$Pu in granulometric fractions Distribution of Sr radionuclide in granulometric fractions

Based on the presented histograms for the radionuclide Am one can note a ralative uniformity of its distribution in granulometric fractions of the soils in zones is studied.

For ^{137}Cs, ^{90}Sr and $^{239+241}$Pu there was revealed a general pattern, particularly in the four samples (761, 725, 838 and 855), taken in zone 1, the prevalence of these radionuclides is seen in the fraction with size of 500-250 micron (for ^{137}Cs in the range of 37.5-54.0%, ^{90}Sr –50.5-70.4%, $^{239+241}$Pu – 30.3-56.9%). In the samples collected in zones 2 and 3, the content of radionuclides in this fraction (500-250 micron) is not predominant, and no more than 18% of the total content.

The $^{239+240}$Pu/^{241}Am ratio in granulometric fractions of soil.

To determine the relationship $^{239+240}$Pu/^{241}Am, the soil samples were prepared in a special way (preparation procedure involves several attrition stages), the attrition quality was controlled by ^{241}Am content in aliquot samples.

The ratios of $^{239+240}$Pu specific activity in soil granulometric fractions to the specific activity of ^{241}Am are shown in Table 18.

Table 18.

$^{239+240}$Pu/^{241}Am ratios in granulometric fractions

Zone	Point №	1,000 – 500 micron (28%)	500 – 250 micron (17%)	250 – 100 micron (15%)	100 – 63 micron (15%)	63 – 40 micron	< 40 micron
		$^{239+240}$Pu/^{241}Am	$^{239+240}$Pu/^{241}Am	$^{239+240}$Pu/^{241}Am	$^{239+240}$Pu/^{241}Am	$^{239+240}$Pu/^{241}Am	$^{239+240}$Pu/^{241}Am
1 Zone	761	13.6	45.4	47.1	4.7	11.4	5.9
	725	16.2	36.0	29.5	11.7	11.1	10.1
	838	35.2	39.3	14.7	17.7	8.1	7.6
average, Zone 1		21.6	40.2	**30.4**	**11.4**	**10.2**	**7.8**
Zone 2	189	**3.8**	**8.4**	**6.2**	**11.9**	**5.2**	**5.9**
Zone 3	424	3.2	2.5	5.5	10.3	3.4	4.2
	365	1.5	2.6	5.6	3.8	2.2	3.6
	258	2.6	4.6	2.4	3.2	3.4	11.9
average, Zone 3		**2.4**	**3.2**	4.5	5.8	3.0	6.6

Research results reveal three main features. First, there is clear difference of Zone 1, which is characterized by high ratios of $^{239+240}$Pu/ ^{241}Am in granulometric fractions, compared with soils of 2nd and 3rd zone. A similar pattern is observed ratio of radionuclides in soils considered areas (not separated into fractions). Recall, these ratios, on average, equal to one area – 17.9. for the zones 2 and 3 – 7.0 and 5.14, respectively.

Another important fact is that in soils of Zone 1 the ratio of $^{239+240}$Pu/^{241}Am is the highest in the first three fractions of soil – 1000-550, 500-250 and 250-100 micron, pollution of which may be caused, first of all, by the "local" tests.

The third feature concerns the smallest soil fraction of three considered areas < size 40 micron, where relationships of radionuclides is characterized by low levels, an average, 7.8 for zone 1, 5.9 for 2nd zone and 6.6 for 3rd zone.

2.3.4. Soil quality assessment

The natural conditions of the study area determine the suitability of the land for use. The study area is mainly livestock. Rugged terrain frequently covered with a thin layer of fine grained soil and extensive broken stone formations prevent from arable activities on these lands. Low-hill terrain, slopes of ridgy spurs, as well as high and low upland is the most suit-

able for pastures. Plant complexes with feather grass, fescue, steppe grasses with scattered bushes meadowsweet, pea shrub and others growing on zonal light chestnut soils are most are suitable forage for cattle in the region [20].

The most productive pastures are located in the lower parts of the slopes on light-brown poorly developed or normal soils, especially the northern exposure, where moisture retains better and thus more significant productivity of grassland. The upper parts of deluvial-proluvial inter-upland plains with significant surface slopes, often have meadow brown soils, where yields of forage grasses increases. At the center of depressions these soils become meadow alkaline and solonchak soils, solonetz and salt marsh under halophytic vegetation with wormwood. Such foods are considered unsuitable for cattle.

Field work revealed the presence of pasture degradation in the study area. The cause of rangeland degradation is mainly grazing livestock. Overgrazing against specific natural conditions of the arid zone causes an intense degradation of land-vegetative cover, which is particularly evident in 2-3 km wide band, adjacent to wintering sites. This area is sometimes trampled causing complete vanishing of vegetation. Upon that, the soils become subject to the upper horizon densification, which result in deterioration of their water-physical properties: increase in bulk density, moisture reduction, disruption of soil structure. In case of sparse vegetation with a yield 0.05-0.1 kg/ha, it is represented by aggregations of various species of wormwood, cypress and other plants that cattle don't like to eat. It should be noted that cattle grazing in these areas for many years has resulted in not only disappearance of vegetation, but also in change in the dominant plant communities, thus different types of grasses, fescue, steppe grasses are replaced by sagebrush and other weed species. Such grazing is considered "battered".

Climatic conditions of the region play a major role in the degradation of pastures. Irregularity of the terrain and soil desiccation in arid climate makes the soil "vulnerable", subject to wind erosion and deflation. The soil in these conditions is sprayed with a loss of humus in the upper horizon and loses fertility. This decreases both all loose layer and humus horizon [21]. Such soil, subjected to wind erosion, ie deflated soil will not be able to restore its original vegetation.

However, field observations indicate the the acreage of land, removed from the agricultural operations due to soil degradation, constitute less than 30% of the total farmland area, which makes it possible to consider this situation as relatively satisfactory [22].

Thus, in the study area mainly non-overgrazed or slightly overgrazed grasslands are distributed, and soils considered non-deflated or poorly deflated. Exceptions are grazing around encampment, watering ponds, winter camps, where pastures are non-overgrazed, soils are medium, strongly diflated, that requires melioration measures and long recovery period for rehabilitation.

2.3.5. Forecast for changes in radionuclide contamination in soils

Radionuclide contamination of upper soil within the "south-east" part of Semipalatinsk Test Site maight have been caused by fallouts from radioactive clouds resulted from nuclear tests performed at "Experimental Field" testing ground. There are some insignificant amounts of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu radionuclides registered in the surficial soil horizons. With the depth radionuclide concentration in the soil profile is greatly reduced, as shown by the data in Table 22, with a maximum value usually remaining in the surface layer.

Thus, despite the length of the last period (50-60 years) since the atmospheric tests, the maximum content of radionuclides deposited on the surface of the soil retains in the surface layer and the depth of penetration into the soil does not exceed 15-20 cm. This behavior of radionuclides is due to the drastic shortage of moisture (precipitation – 200-250 mm), which does not allow them to move into solution or move down by water flow. On the other hand, the amount of evaporated moisture is 4-5 times higher than the amount of precipitation, which leads to the accumulation of soluble salts, including the soluble part of the radionuclides, in surface soil horizons. These findings lead to the prediction that in the future pattern of radionuclide distribution will remain the same, but the content will reduce in the upper horizon and slightly increase the depth of penetration, because, despite the shortage of water, the redistribution of substances and elements in soils happen in geologic time.

It can be assumed that if artificial radionuclides after 50 years since the nuclear tests moved to a depth of 15 cm, and further their penetration rate would remain the same, which is about 0.3 cm per year.

The wind as the relief shaping in a continental development of the region, will continue to play a role in spatial redistribution of radionuclides. So, with the dust particles of <100 micron a part of radionuclides can be suspended in the surface layer, and can be carried away during storms or high winds above 10 m/s over long distances. Dust particles from 100 to 500 micron are the most active parts in the dust storms, the frequency of which in spring and fall can be maximized. About 50% of radionuclides constitute these particles. Consequently, this number of radionuclides is very rare, not more than 4-5 times a year, but may be involved in the movement in space. Soil particles larger than 500 micron can be dragged by vortices at such a wind speed. The particles can also be moved at short distances by sudden changes in a flaw. Thus, deflationary processes can gloss over the boundaries of the former radioactive fallout cloud trails and dilute the concentration of radionuclides in the soil cover.

2.4. Condition of waters

General description of waters in the studied territories

In the course of the studies the water use facilities located throughout the area investigated were searched for and accounted. Analysis of that information revealed that the water objects are both surface waters (mostly temporary temporary stream flow and small lakes) and groundwater – boreholes and wells located apart or close to summer and winter pastures. All water use objects are natural water sources, and potentially can be, and in some cases are, objects for drinking and household purposes.

The main economic activity in the area is livestock – breeding and grazing of black and smal cattle. Since the surface water is salty and greatly salty, for livestock watering they mainly use underground waters taken from the boreholes and wells. Given that in the study area residential summering and wintering sites were found, there is potential for the use of water from the water-use facilities, not only in economic, but also for drinking.

Currently there is no information on the availability of registered water use facilities in the STS. In order to search for and account of all water facilities and make a complete list of them, originally works were carried out with modern hydrogeological maps of the study area. All water use objects, found on the maps, including temporary surface streams, lakes, and areas of possible breeding domestic animals, were included to preliminary survey

scheme, and followed by expeditions directly to their location. The bulk of water facilities was found by the existing coordinates of their location, some of them were found during the visual examination of the area. The coordinates of the objects found were recorded and mapped.

The field survey included:

- visual examination of water objects, photography;
- measurement of radiation parameters (EDR, β-particles flux density);
- status of water body (active/inactive, presence/absence of water, presence of residential buildings around, residence of people, grazing, etc.);
- identification of causes and extent of water object use (if possible), as well as its status in terms of possible future use for drinking, agricultural and other purposes;
- determination of groundwater level (in wells and boreholes);
- determination of water temperature;
- water sampling for analytical studies.

Water was sampled in accordance with GOST 51592-2003 [23].

The samples were collected in 2-30 liters plastic containers, depending on the laboratory test type.

In total, in the study area 42 water objects were identified and examined. Most of the objects are wells and boreholes, fenced with concrete structures, water troughs for livestock watering.

Because some of the examined water objects look abandoned and destroyed, dilapidated, or heavily littered, water could only be sampled from 35 water use facilities. Of them – 14 are surface water streams, 11 – wells, and 10 – boreholes. Brief description of all water facilities is provided in Figure 24.

The field studies revealed that the water table in the area ranges from 1.0 to 6.8 m. The underground water temperature varies from 5 to 10°C, the surface – from 9 to 15°C.

The examination established the presence of eight water facilities located in the residential summer pastures and wintering sites both for permanent and temporary use. They are water facilities located on the territory of wintering sites Tolegen (t.345), Zhanadar (t.279), Karashoky (t.341), Sunkar (t.357), Dostar (t.342V), and villages Samai and Ainabulak and borehole t.377 located near unnamed residential wintering site.

To assess the quality of water and the degree of its suitability for drinking or household purposes in all objects water was sampled for laboratory, chemical, trace element and radionuclide composition.

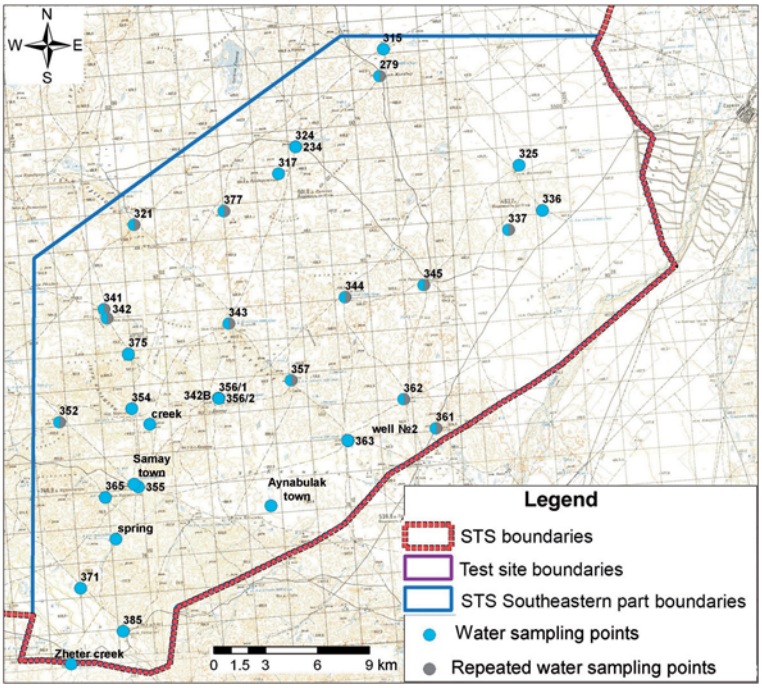


Figure 24. Location of water objects

2.4.1. Assessment OF water quality by general chemical characteristics

For a preliminary assessment of water quality in water use facilities located in the southeastern part of the STS the water samples were analyzed in the laboratory to determine the following: chloride, sulfate, total hardness, total salinity (mineralization) [24].

By salinity (Vernadsky's classification) the fresh waters are those with salinity (mineralization rate) up to 1,000 mg/dm^3. Brackish – from 1,000 to10,000 mg/dm^3. Salty water – from 10,000 to 0000 mg/dm^3, the brine water – over 50,000 mg/dm^3.

Based on the analysis the water in the waters objects under study was described as follows.

By salinity degree most of the water samples pertain to brackish (1,180-7,380 mg/dm^3) – 60 % and fresh (up to 920 mg/dm^3) – 33 %. A small part of samples pertain to the salty (16,000 mg/dm^3 and 23,000 mg/dm^3) – 7 %. According to the Sanitary Regulations and Standards, the total salinity should not exceed 1,000 mg/dm^3.

By its anion content, water mostly pertain to the sulphate-hydrocarbonate-chloride, sulfate-chloride-hydrocarbonate, hydrocarbonate-sulfate-chloride type of water. By chloride and sulphate content 36.7 % of water meets SanPiN (Sanitary Regulations and Standards) standards (up to 500 mg/dm^3 to 350 mg/dm^3 respectively).

The data obtained show that 10 % of investigated water samples pertain to soft (less than 4 mg-eq/L), 20 % – to moderately hard (4-8 mg-eq/L), 16.7 % – to hard waters

(8–12 mg-eq/L), 53.3 % – to a very hard (more than 12 mg-eq/L). Small part of water samples (30 %) meets SanPiN (over 12 mg-eq/L).

Water pH ranges from 5 to 7.5 (average – 6.5). About 43.4 % of water samples (within 9.6 pH units) meet Sanitary Regulations.

Thus, of all the analyzed water samples collected in the southeastern part of the ST, the chemical composition parameters of 8 water samples meet all Sanitary Standards and this water is suitable for drinking and household purposes. They are water objects numbered 336, 321, 175, 179, 354, 361, 375 and 325.

Waters from other objects are not desirable to use for drinking because of the increased total salinity and hardness. The water in the water objects, numbered 337, 345 and 214 (surface water sources) is not recommended for use as total salinity and hardness is respectively 5, 10 and 15 times higher than the SanPiN standards.

2.4.2. Quality assessment of water facilities by their trace element composition

The trace-element analysis of the samples investigated water concentration of key trace elements, which are I-III class of hazard by its biological role. They include Be, Hg, B, Ba, Cd, Co, As, Pb, Al, Zn, Ni, etc.

The concentrations of the elements under study were compared with MPC – maximum permissible concentration by standards of SanPiN № 4.01.071.03 [25].

The results in the water samples tested we did not detect such trace elements as Hg (0.0005 mg/L), Cd (0.001 mg/L), Co (0.01 mg/L), As (0.05 mg/L), Pb (0.03 mg/L) and Zn (5 mg/L). All the values for these elements are lower than the maximum permissible concentration (MPC) in drinking water.

The exceedance of beryllium permissible levels was found in eight water facilities that are surface water sources, numbered 365, 352, 354, 375, 355, 361, 336, 315. The concentrations of beryllium in water samples, taken from these water facilities, range from 0.00025 to 0.0077 mg/L. In all other water facilities located in the study area, the beryllium content in the water is well below the maximum permissible concentration, which is 0.0002 mg/l.

The boron content in the examined water samples ranges from 0.07 to 3.3 mg/L, which in most cases, exceeds the standards for content in drinking water almost an order of magnitude. The parameters obtained exceed the established norms in almost all samples. The MPC for the content of this trace element in the water should not exceed 0.5 mg/l.

Aluminum concentration in the water samples ranges from 0.02 to 37 mg/l. Maximum concentrations of aluminum were observed in the surface water body – lakes in t.336. The concentration limit for aluminum content in drinking water is 0.5 mg/L (SanPiN).

The maximum permissible concentration in drinking water for barium is 0.1 mg/l. According to the results of laboratory studies, the concentrations of barium slightly exceed in 7 out of all taken water sample from the water facilities, numbered 354, 375, 361, 325, 315, 357 and 362. In the facility numbered 336 (lake) barium concentration is exceeded by more than an order of magnitude and is 1.4 mg/l. In all other water samples the barium content is normal and varies from 0.0023 to 0.1 mg/l.

The nickel content in the water facilities varies from 0.001 to 0.08 mg/l. Slight excess in nickel concentration was detected in 8 of the investigated objects – t.336 (lake), stream Zheter, boreholes in t.234, t.362, t.279, wells in t.343, t.344 and t.213. According to the standards of drinking water quality, the nickel content should not exceed 0.02 mg/l.

Thus, an excess in concentrations of certain trace elements in the water samples examined was recorded in 27 out of all the surveyed water facilities, located in the territory. Of these, 6 boreholes, 4 wells and 17 surface water sites. A slight excess of the maximum permissible concentration in water was observed for aluminum, boron, barium, nickel.

Elevated concentrations of beryllium, the most toxic of all the above elements, were detected only in surface water sources, the water in which is heavily salty and is not suitable for use for drinking purposes.

The water in all other water facilities located in the area, in terms of trace element composition concentrations, meets the standards and requirements of the quality of drinking water and can be used without restriction for drinking, household or other uses.

2.4.3. Contents of artificial radionuclides in surface and ground water of the studied region

To study the levels of contamination with artificial radionuclides the water samples from all water facilities were analyzed for ^{3}H, ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ [26, 27]. The results are shown in Table 19.The detection limits of the used hardware and methodological support averaged 0.02 Bq/L for ^{90}Sr and ^{137}Cs, 15 Bq/l for tritium and 0.001 Bq/l for $^{239+240}Pu$, which is below the MPC for these isotopes 10-1000 times.

Table 33.

Specific activity of artificial radionuclide in water

№	Sampling point	Specific activity ^{137}Cs, Bq/kg	Specific activity ^{90}Sr, Bq/kg	Specific activity $^{239/240}Pu$, Bq/kg	Specific activity ^{3}H, Bq/kg
1	371	<0.1	<0.01	<0.09	<8
2	365	<0.02	<0.02	-	<15
3	352	<0.02	<0.02	<0.0026	<15
4	354	<0.02	< 0.02	-	40
5	375	<0.02	<0.01	<0.001	30
6	355	<0.04	<0.01	-	<8
7	385	<0.05	<0.02	<0.015	<9
8	361	<0.04	<0.01	<0.004	<12
9	borehole 325	<0.01	<0.02	<0.008	<8
10	lake 336	<0.05	<0.01	<0.00062	<9
11	borehole 345	<0.02	<0.01	<0.0007	<9
12	Surface water 337	<0.01	<0.01	<0.004	<10
13	borehole 324	<0.03	<0.01	<0.0065	<8
14	borehole 279	<0.01	<0.01	<0.00067	<8
15	Surface water 315	<0.01	<0.01	<0.00084	<9
16	borehole 317	<0.03	<0.01	<0.030	<7
17	borehole 377	<0.04	<0.01	<0.003	<7
18	borehole 321	<0.01	<0.01	<0.0035	<7
19	341	<0.01	<0.01	<0.001	<7
20	342	<0.02	<0.01	<0.002	<8
21	borehole 356/1	<0.01	<0.01	<0.002	<7
22	well 356/2	<0.02	<0.01	<0.0017	<8
23	borehole 343	<0.01	<0.01	<0.00082	<8

№	Sampling point	Specific activity ^{137}Cs, Bq/kg	Specific activity ^{90}Sr, Bq/kg	Specific activity $^{239/240}$Pu, Bq/kg	Specific activity ^{3}H, Bq/kg
24	357	<0.01	<0.01	<0.0034	<8
25	344	<0.04	<0.01	<0.0027	<9
26	363	<0.02	<0.01	<0.012	<8
27	362	<0.02	<0.01	<0.004	<8
28	Smai village, well	<0.02	<0.004	<0.0008	<12
29	Zheter stream	<0.03	<0.004	<0.0012	<13
30	Unknown stream (Neizvestny)	<0.02	<0.004	<0.0014	<14
31	well 342B	<0.02	<0.004	<0.0018	<12
32	borehole 234	<0.02	<0.005	<0.0008	<12
33	Spring	<0.01	<0.004	<0.0013	<14
34	well №2	<0.02	<0.006	<0.0019	<12
35	Ainabulak village, boreholes	<0.02	<0.005	<0.0027	<12

The laboratory data analysis showed that concentrations of ^{3}H, ^{137}Cs, ^{90}Sr and $^{239+240}$Pu are below the detection limit of the methods used and equipment and amount to <0.09 Bq/kg, which does not exceed the established norms for content of artificial radionuclides in water. According to Kazakhstani Hygienic Standards "Sanitary Requirements for Radiation Safety" the intervention level at intake with water for ^{3}H is 7600 Bq/kg, ^{137}Cs – 11 Bq/kg, ^{90}Sr – 4.9 Bq/kg, $^{239+240}$Pu – 0.55 Bq/kg [28].

In accordance with the regulations in force in the Republic of Kazakhstan [28, 25] – Hygienic Standards SanPiN № 2.1.4.1074-01 "Sanitary and epidemiological requirements for quality of centralized water supply systems", the water from water facilities, located in the southeastern part of the STS was assessed for quality. Water quality assessment was carried out by laboratory methods using standard equipment and verified equipment.

General water chemistry study results show that fully usable water is in objects numbered 336, 321, 175, 179, 354, 361, 375 and 325. The water in the other water sites is recommended for limited use due to exceeding the parameters of the total hardness and salinity.

According to the radionuclide analysis in all water objects investigated the specific activities of artificial radionuclides are below the detection limit and do not exceed the intervention level at intake with food and water, according to the Kazakhstani Hygienic Standard "Sanitary Requirements for Radiation Safety" [28].

Trace element study results concluded that the water in almost all water use facilities, by its trace elements in it, is satisfactory and suitable for use for drinking or other purposes.

Exceptions are objects in the water of which we detected beryllium. Given that the water objects are of natural origin, and all are classified as surface waters, this might be the case, but one should know that this water is not recommended for drinking water.

2.4.4. Forecast of changes in radionuclide contamination of surface and groundwater

A full assessment of the lands to be transferred requires not only the data on levels of radionuclide concentration in groundwater, common on the STS testing grounds, but

also forecasts of the possible migration of contaminated groundwater from UNE venues to groundwater of these areas.

Data on the geological structure and hydrogeological conditions, and the mechanisms of radioactive contamination of water environment in zones where nuclear testing in the STS was done are presented in detail in the materials on the "northern" areas [29]. This chapter will focus on the review and assessment of possible pathways of contaminated groundwater migration from the underground nuclear explosion (UNE) of into groundwater of "south-east" territories. The possibility of contaminated groundwater flow from the atmospheric nuclear explosion and warfare radioactive agent testing sites into the groundwater of the study area is not considered because these test sites are located 88 km from the northern boundaries of the southeastern territories. The main direction of the regional groundwater flow from the testing grounds is north and north-east. I.e. groundwater from the testing grounds flows almost the opposite direction from the "south-east" territories.

Thus, we do not expect flow of contaminated groundwater from the atmospheric nuclear explosion and warfare radioactive agent testing sites into groundwater of "southeast" areas.

When considering the likelihood of contaminated groundwater flow from the UNE venues into groundwater of "southeast" territories the following factors are taken as a basis:

- assessment of existing areas of contaminated groundwater spread threatening to contaminate the waters of the "south-east" territories;
- assessment of the features of the geological structure of the "south-east" territories.

Among the possible sources of groundwater contamination of "south-eastern" areas "Degelen" stands out as the most likely. To a lesser extent we expect contaminated water flow from "Telkem" and "Sary-Uzen". "Balapan" site among the major possible sources also is not considered because it is located at a significant distance from the boundaries of the study area. At this, groundwater from this site flows almost in the opposite direction from the "south-east" territories.

"Telkem" site. Boundary of "Telkem" site is 4 km from the northern boundary of the "southeast" territories. According to the previous test of water wells at "Telkem-1" and "Telkem-2" the concentration of radionuclides in groundwater, distributed within a given area, does not exceed the permissible values for drinking water and reaches the following: ^{137}Cs – up to 2.0, ^{3}H – up to 50, ^{90}Sr – up to 3.0 Bq/kg. Thus, the groundwater of "Telkem" site poses no risk to contaminate groundwater of southeastern STS. Also, the groundwater of "Telkem" is filtered in the north-east direction, i.e. in the opposite direction from the study area.

"Degelen" site. This site is located 17 km from the north-western boundary of the study area. Studies have shown that contaminated groundwater, flowing beyond Degelen Mountain, is confined mainly to the beds of temporary and permanent streams. In our case, groundwater, common in the valley of streams Uzynbulak and Baitles can flow into groundwater of southeastern part of STS. These streams move from mountains in the south and south-east direction.

Underground waters in southwards. These include streams confined to stream beds of Baitles and Tohtakushuk. According to studies, in the groundwater of Baitles stream valley

^{137}Cs content is below MDA equal to ^{137}Cs <0.01 Bq/kg. Quantitative values of ^{90}Sr were established only in two wells containing up to 0.01 Bq/kg. The main radioactive contaminant is ^{3}H, content of which in the groundwater where it goes beyond the mountains is 260 kBq/kg. With distance from the mountains ^{3}H concentration is markedly reduced, but, nevertheless, at a distance of 10 km from the mountain it is 10 kBq/kg.

Underground waters in south-eastward. These include streams flowing beyond the mountain massif through Uzynbulak stream valley. In these waters, ^{137}Cs concentration does not exceed MDA as well (^{137}Cs <0.01 Bq/kg). Quantitative values of ^{90}Sr were established only in two boreholes containing up to 3.0 Bq/kg. $^{239+240}$Pu was detected in three boreholes containing up to 0.7 Bq/kg. ^{3}H concentration in groundwater at boundary of the mountains is up to 200 kBq/kg and then is drastically reduced to acceptable levels for drinking water. To the east, within the southern boundary of the STS, Uzynbulak Valley comes together with Shagan River watershed valley. According to the drilling and testing of water wells in Shagan River waters at conjugation of the no artificial radionuclides were detected.

Thus, the analysis showed that the underground water distributed within the local watershed of Baitles and Uzynbulak, can be a real supplier of artificial radionuclides into groundwater of the southeastern territories. Given the fact that in this area the regional groundwater flow is of north-east direction, then in this case the contaminated groundwater from the Baytles and Uzynbulak base can penetrate the boundaries of southeastern territories only through tectonic faults.

It should be borne in mind that in the southeastern territories is a number of regional faults of northwest strike and major meridian and north-eastern strike.

The largest is the Main Chingiz Regional Fault of northwest strike, the trail of which can be seen in the western part of the study area. The plume of the fault runs near "Degelen" site and on the south-western boundary of "Sary-Uzen" site. In this connection, there are grounds for assuming that contaminated groundwater flow from these sites through this fault.

It should also consider the presence of the West Arkalyk Regional Fault, the line of which is traced 7 km from the north-eastern boundary of the southeastern area. Traditionally, all of the major tectonic faults are accompanied by a series of smaller feathering faults.

Thus, according to the analysis of tectonic patterns and refining their location by space images the tectonic faults were identified for the study as the main way of possible motion of contaminated groundwater from "Sary-Uzen", "Degelen" and "Telkem" sites. To verify this version a method of direct sampling of groundwater was used. In this connection, for the study of interstitial waters areas were identified for drilling 3 water wells to a depth of 60 m, to study pore water – 4 auger-type wells with a depth of 15 m (Figure 25).

Further, to establish the existence of possible motion of polluted water from Degelen Mountain massif and "Telkem" site towards southeastern section through tectonic faults, in near-by territory spots were laid to drill 26 auger-type wells with a depth of 15 m. Main Chingiz fault was a closer attention. In the ipact zone of this fault one core well was drilled to a depth of 60 m and 10 auger-type wells up to 15 m deep (Figure 25). All the wells penetrated the groundwater and were tested.

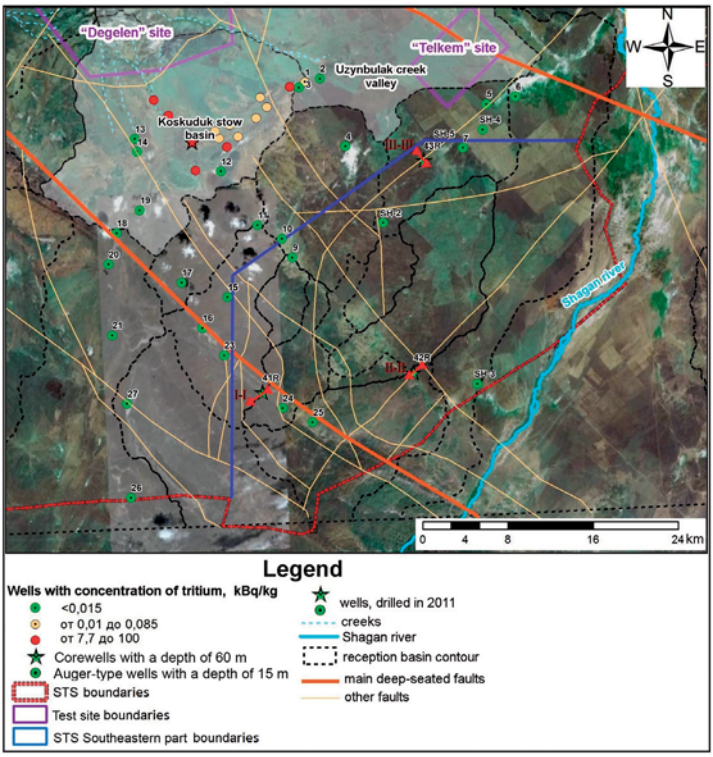


Figure 25. Arrangement of drilled water wells and geophysical profiles

PROGRESS MADE

To study possible migration of artificial radionuclides in the above areas, in 2011 comprehensive studies of groundwater were carried out, including geophysical surveys, drilling, experimental- filtration observations in the drilled water wells and laboratory tests to determine the radionuclide and chemical composition of groundwater samples. As a preliminary, geophysical surveys were performed to determine the main water bearing zones. Based on the geophysical data obtained one hole with a depth of 60 m at each site was drilled to study ground water, confined to faulting zones.

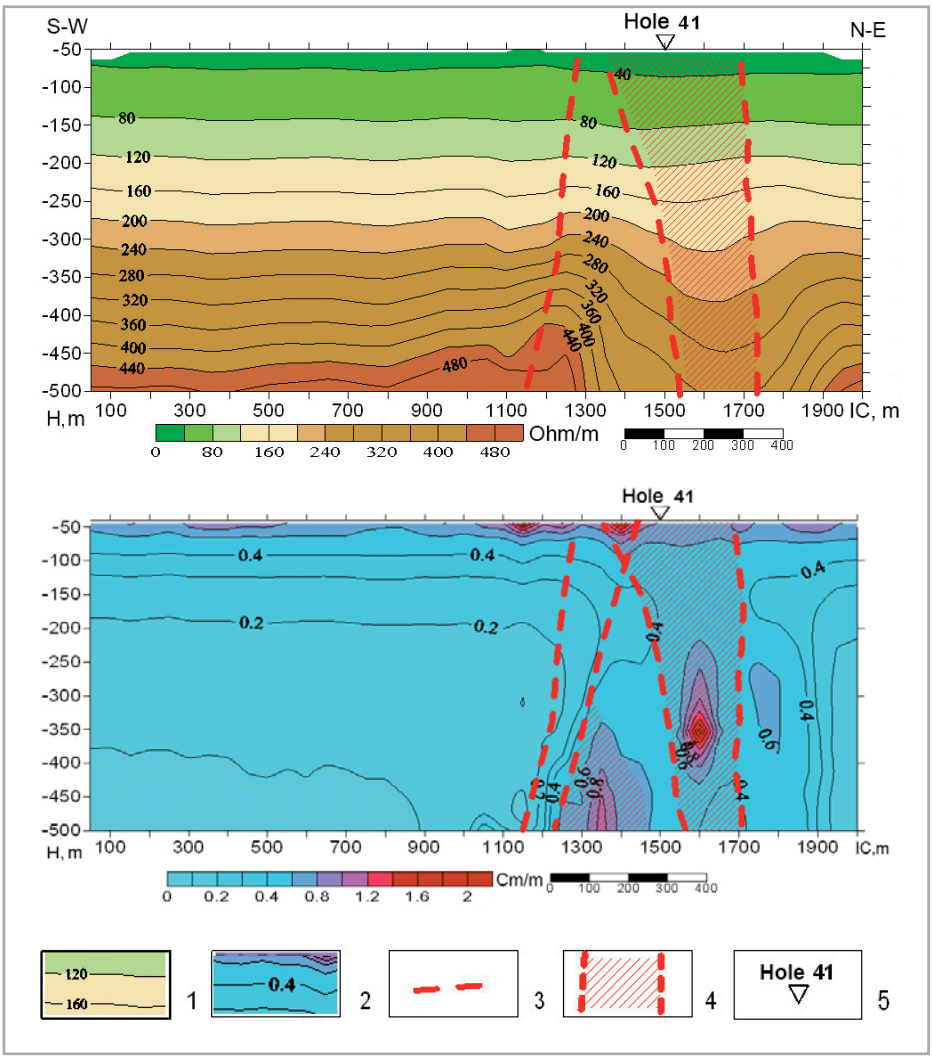
Electrical exploration was performed to identify in section the tectonic disturbances by near-field transient electromagnetic sounding in the form "off-grounded combined loop" [30, 31].

Drilling was made with rig UKB-500S using mechanical rotational method of core sampling. A borehole 132/127-93 mm in diameter and with depth of 62 m was drilled to refine the geological section.

Mail Chingiz Fault plume

Profile1. Figure 23 shows the geoelectric section, based on the near-field time-domain electromagnetic sounding data on profile 1 for depths of 50-500 m in the param-

eters ρτ-longitudinal electrical resistance (Figure 26a) and Sτ-longitudinal conductivity (Figure 26b).



1 – isolines of electric resistance ρτ; 2 – isolines of electric conductivity Sτ;
3 – tectonic faulting line by geoelectric data, 4 – flooded fractured zones, 5 – twinned hole.

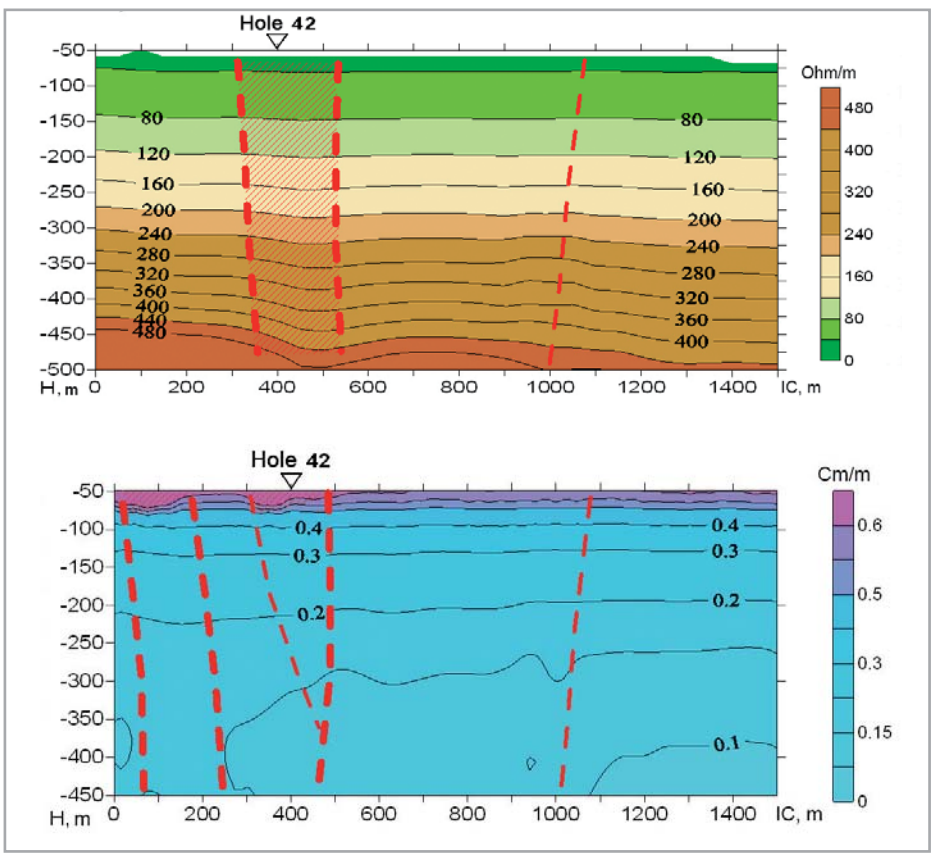
Figure 26. Main Chingiz Fault plume. Profile 1. Geoelectric section in the parameters:
a – electrical resistance ρτ; b – longitudinal conductivity Sτ

At this profile the tectonic disturbance is contrasting both at the electric resistance, and on the longitudinal conductivity. An important characteristic of the fractured zone structure is its heterogeneity, and the presence of local areas (Stake 1250-1700) with significantly higher

longitudinal conductivity at depths of 250-400 m (Stake 1550-1750), and a depth of 350-500 m (Stake 1200-1500). These intervals are interpreted as watered zones. Among the flooded zones the most contrasting is the zone in the range of 1350-1700, therefore a borehole 41 was drilled to a depth of 60.2 m (Figure 43). Boreholehole 41 in the upper part to a depth of 3.5 m met clay, and then to 9.0 m – fractured sandstones. Between 9.0m and 60 m the section is folded of siltstones. Underground water level in the borehole established at a depth of 5.0 m. Based on the experimental pumping we determined the filtration coefficient – 0.12 m/day and pumping flow rate – 0.12 l/s (10.4 m³/day), specific flow rate was 0.011 l/s (1.02 m³/day). The aquifer has little pressure. Thus, the host rocks of the aquifer are slightly permeable.

The East Chingiz Fault plume

Profile 2. Figure 27 shows the geoelectric section ρτ and Sτ on profile 2 (depth range 50-500 m).



See Figure 23 for Legend

Figure 27. The East Chingiz Fault plume. Profile 2. Geoelectric section in the parameters: a – electrical resistance ρτ ; b – longitudinal conductance Sτ

By the ratio of the longitudinal conductance gradient two sub-horizontal geoelectric boundaries at depths of 80 and 130 m were identified. By the electrical resistance there were revealed tectonic disturbances in between 350-550 which is practical interest for detection of fracture watercut of effusive rocks. Most contrasting it is at the depths of 500-700 m and can be traced to a level 70-150 m. A characteristic feature of this zone is significant lower contrast against electrical resistance in comparison to the zone on the profile 1. By the change in the isoline configuration of this parameter, other tectonic disturbances with contours with varying degrees of probability were identified. Among them the flooded fracture zone are intervals 0-180 and 300-400 with the distribution depth not more than 70-80 m.

Within the zone identified between 350 and 550 a borehole 42 was drilled to a depth of 48 m. In the upper part (to a depth of 3.0 m) the borehole crossed the medium-grained sand with fine gravel, then – to a depth of 12 m – the weathering crust of andesitic porphyrite and up to 48.0 m – andesite porphyries. Rocks along the entire borehole section are fractured, watercut. Underground water level in the borehole established at a depth of 4.0 m. Based on the experimental pumping we determined the filtration coefficient – 0.002 m/day and flow rate – 0.037 l/s (3.2 m^3/day), specific flow rate was 0.003 l/s (1.02 m^3/day). The aquifer has little pressure. Thus, the host rock of the aquifer is slightly permeable.

Arkalyk Fault plume

Profile 3 is laid on the area folded with diorites and granodiorites. Geoelectric section along the line of the profile (Figure 28) reveals the block structure of the geological section. A characteristic feature of the geoelectric section for profile 3 is the presence of steeplydipping conductive zone mapped in the range stake 250-420.

Based on the data between stakes 300-400 a 63 m deep well 43 (Figure 28) was drilled, which revealed the clay (to a depth of 12.0 m), diorites (up to 53.0 m) and granodiorite (up to 63 m). Diorites and granodiorites are fractured, flooded. Underground water level established at a depth of 3.5 m.

The experimental pumping results defined filtration coefficient – 0.04 m/day and flow rate – 0.71 l/s (61.3 m^3/ day), specific flow rate was 0.06 l/s (5.2 m^3/day). Aquifer is little pressure.

Contamination of groundwater with artificial radionuclides

The results of laboratory analyzes of groundwater samples taken from the water wells drilled in 2011, are presented in Table 20. Concentration of tritium was determined in all wells. ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ were determined only in wells drilled directly on the area south-eastern part of the STS.

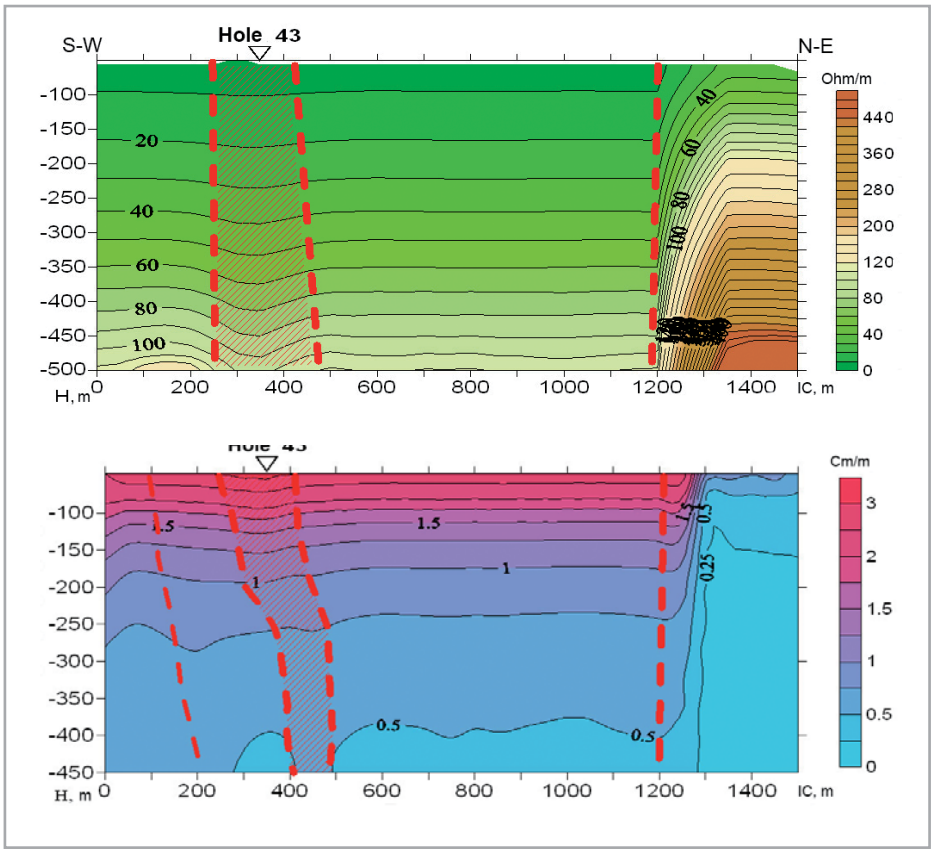


Figure 28. Arkalyk Fault plume. Profile 3. Geoelectric section in the parameters:
a – electrical resistance ρτ ; b – longitudinal conductance Sτ

Table 20.

Results of laboratory analyses

№	Borehole №	Coordinates						^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
		north latitude			east longitude						
		°	`	``	°	`	``				
1	III-4	49	39	27.80	78	30	6.30	<12	-	-	-
2	III-5	49	38	50.90	78	26	28.50	<13	-	-	-
3	III-2	49	34	59	78	22	1.8	<14	<0.01	<0.005	<0.0012
4	III-3	49	26	36.40	78	28	46.40	<12	<0.01	<0.004	$<0.11*10^{-6}$
5	41 P	49	26	40.4	78	12	7.6	<10	<0.05	<0.005	$<1.2*10^{-3}$
6	42 P	49	27	21.5	78	23	54.7	<12	-	-	-
7	43 P	49	38	5.50	78	25	24.80	<13	-	-	-
8	boreh. 2	49	42	25.10	78	17	36.20	<13	-	-	-
9	boreh. 3	49	42	0.50	78	15	55.00	<13	-	-	-
10	boreh. 4	49	38	56.00	78	19	22.10	<12	-	-	-

№	Borehole №	Coordinates						^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
		north latitude			east longitude						
		°	`	``	°	`	``				
11	boreh. 5	49	40	44.80	78	30	28.50	<13	-	-	-
12	boreh. 6	49	41	3.60	78	32	46.20	<12	-	-	-
13	boreh. 7	49	38	35.40	78	28	30.40	<12	-	-	-
14	boreh. 9	49	33	24.70	78	14	51.10	<13	-	-	-
15	boreh. 10	49	34	23.50	78	14	6.20	<13	-	-	-
16	boreh. 11	49	35	8.10	78	12	14.90	<12	-	-	-
17	boreh. 12	49	37	56.00	78	9	33.90	<14	-	-	-
18	boreh. 13	49	39	45.70	78	2	58.50	<12	-	-	-
19	boreh. 14	49	39	6.10	78	3	5.70	<13	-	-	-
20	boreh. 15	49	31	32.90	78	9	40.80	<12	-	-	-
21	boreh. 16	49	30	2.10	78	7	38.20	<12	-	-	-
22	boreh. 17	49	32	22.80	78	6	9.20	<15	-	-	-
23	boreh. 18	49	35	1.50	78	1	15.40	<12	-	-	-
24	boreh. 19	49	36	7.90	78	3	8.10	<13	-	-	-
25	boreh. 20	49	33	27.30	78	0	32.40	<13	-	-	-
26	boreh. 21	49	29	51.30	78	0	35.80	<12	-	-	-
27	boreh. 23	49	28	36.60	78	9	13.50	<12	-	-	-
28	boreh. 24	49	25	48.40	78	13	35.40	<12	-	-	-
29	boreh. 25	49	25	1.70	78	15	52.40	<13	-	-	-
30	boreh. 26	49	21	35.10	78	1	32.90	<12	-	-	-
31	boreh. 27	49	26	21.40	78	1	32.90	<13	-	-	-

Laboratory tests showed that the concentrations of radionuclides in groundwater both in southeastern parts of the STS, and in adjacent areas do not exceed MDA.

According to the results, in groundwater of the STS southeastern part concentrations of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{3}H are below the detection limit and do not exceed the intervention level at intake with food and water, according to HS SRRS [28].

Studies have shown that groundwater, contaminated with artificial radionuclides and flowing beyond the Degelen Mountain in the south and south-east, is located within the local watershed of Koskuduk and Uzynbulak and does not migrate outside the watersheds through tectonic disturbances in the "south-eastern" areas.

Thus, the results of the studies suggest that the levels of radioactive contamination of groundwater in the STS "southeast" territory can be used in all kinds of agricultural activities without any restrictions.

2.5. THE AIR BASIN

Radioactive contamination of air basin in the former Semipalatinsk Nuclear Test Site might have been caused by the following factors:

- large areal sources of contamination, such testing grounds as "Experimental field", "Sary-Uzen", "Warfare Radioactive Agents" testing, "Balapan", "Telkem" sites, as well as radioactive fallout plumes from atmospheric nuclear testing;

- surface and underground waters, the evaporation of which results tritiated water tritium (Shagan River section, surface water and groundwater of Degelen mountain) to get into air.

Currently, the risk is mainly due to the following radionuclides – ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}Pu$ and ^{241}Am. Based on the physical properties of these radionuclides (alpha and beta emitters), the greatest danger that they pose is in case of an internal exposure.

The most likely source of secondary air pollution in the study area may be areal contamination areas located at "Telkem" site.

Studies performed to assess the air basin state at the southeastern part of STS followed the methodology: theoretical assessment of contamination, field and laboratory studies. During the field works we sampled air, vapour, measured radon and thoron equivalent equilibrium volume activity (EEVA), density of surface exhalation for radion. Laboratory studies covered sample preparation and volume activity determinations for artificial and natural radionuclides. Additionally, radon hazards at the territory were assessed.

Sampling and measurement of EEVA of radon, thoron were conducted on residential wintering site and summer pastures in summer of 2010-2011 (Figure 1, Table 24).

2.5.1. Theoretical assessment of the content of natural and artificial radionuclides in air of the studied area

The results of the study determined that in the "south-east" of the STS 3 zones were identified for which we calculated average specific activity of artificial radionuclides in the surface soil layer.

The climatic conditions in the study area (dust storms, high winds) contribute to the secondary rise of artificial radionuclides contained on the soil surface. This process is also forced by the spread of the light soils there that are most susceptible to dusting. Therefore in the theoretical estimation it is advisable to consider radionuclide content in the fine fraction (<40 micron), which will take part in the resuspension and transport at a wind speed of 6 m/s.

A study of granulometric composition determined that 14% of the total weight of the soil accounts for the fine fraction (<40 micron). Table 21 shows the contents of radionuclides ^{137}Cs and ^{241}Am in surface soil (3 cm) in a faine granulometric fraction.

Table 21.

Contents of the radionuclides in the granulometric fractionразмером <40 μm of studied soil

Average content of radionuclides in the granulometric soil fraction <40 μm, %	
^{137}Cs	^{241}Am
17.6	9.6

Given the average content of the fine fraction and average specific activity of artificial radionuclides in the soil, the average percentage of radionuclides in this fraction, and the ratio of radionuclides within the zones (Table 7), we can calculate the specific activity of radionuclides in the fine fraction of the soil. The results are presented in Table 22.

Table 22.

Specific activity of radionuclides in the fine fraction (<40 μm) of soil

Average specific activity, Bq/kg			
^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Zone 1			
32.3	4.9	13.0	1.4
Zone 2			
47.7	3.6	10.4	1.1
Zone 3			
30.8	3.7	4.3	0.7

Assessment of artificial radionuclides content in air of the southeastern part of STS was performed based on average specific activities in the zones I, II and III. Initial data are presented in Table 22.

Calculated volume activities of artificial radionuclides in air are presented in Table 23 taking into account year-average dustness of the air.In assessing the content of artificial radionuclides in the air, we take into account the specific activity of radionuclides in the granulometric fraction of soil <40 micron.

Theoretical evaluation of the content of artificial radionuclides in the air was performed assuming a resuspension factor.Volume activity of radionuclides in the air of "southeastern" parts of the STS was calculated as [3]:

$$C_{air} = C_i \ \rho_{sus} ,$$

where:

C_{air} – activity concentration of the i-th radionuclide in the air (Bq/m^3);C_i – specific activity i-th radionuclide in surface soil, Bq/kg;

ρ_{sus} – annual average air dustiness, kg/m^3.The average annual natural air dustiness, according to [33], outdoors and indoors is $1 \cdot 10^{-7}$ kg/m^3. During natural or man-made dustiness the air dustiness can increase up to 10 times, that is, to $1 \cdot 10^{-6}$ kg/m^3. In assessing the content of radionuclides in the air the air dustiness value is accepted to be $1 \cdot 10^{-6}$.

The artificial radionuclides in the air of the "south-east" parts of the STS were assessed by the average specific activity in zones 1, 2 and 3. Baseline data are shown in Table 22.The calculated activity concentrations of artificial radionuclides in the air of the study area with the average annual air dustiness are given in Table 23.

Table 23.

Volumetric activity of artificial radionuclides in the air of STS southeastern part

Annual average air dustiness (ρ_{sus}), kg/m^3	Volume activity of radionuclides in the air at average specific activity in the soil, Bq/m^3			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
	Zone 1			
10^{-6}	$3.2 \cdot 10^{-5}$	$4.9 \cdot 10^{-6}$	$1.3 \cdot 10^{-5}$	$4.9 \cdot 10^{-6}$

Annual average air dustiness (ρ_{sus}), kg/m^3	Volume activity of radionuclides in the air at average specific activity in the soil, Bq/m^3			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
	Zone 2			
10^{-6}	$4.8\cdot10^{-5}$	$3.6\cdot10^{-6}$	$1.0\cdot10^{-5}$	$3.6\cdot10^{-6}$
	Zone 3			
10^{-6}	$3.1\cdot10^{-5}$	$3.7\cdot10^{-6}$	$4.3\cdot10^{-6}$	$3.7\cdot10^{-6}$
$PVA_{population}$, Bq/m^3	$2.7\cdot10^{1}$	2.7	$2.5\cdot10^{-3}$*	$2.9\cdot10^{-3}$
Note: * – permissible activity concentration of $^{239+240}$Pu was adopted to be $2.5\cdot10^{-3}$ for one radionuclide ^{239}Pu				

The obtained activity concentration of artificial radionuclides in the air of "south-east" parts of the STS at average specific activity in the surface soil in zones 1, 2 and 3 is much smaller (by 2 – 6 orders of magnitude) than permissible values, according to HS SRRS [28].

Calculations showed that volumetric activity of artificial radionuclides in the air over studied area should not exceed the regulatory levels even at maximal possible dustness and in presence of maximal radionuclide concentrations in air.

2.5.2. Experimental data on the content of natural and artificial radionuclides in the air of the study area

During roinassance we described the inhabited locations at the studied territory (population, location, etc.). The largest settlements evenly distributed over the area were chosen for air pollution studies. Surveying of each inhabited location followed the same methodology – sampling of air, vapour, and determination of radon hazard. The air sampler was placed in the center of the village. The us each air aerosol sample was taken for 4 hours. Water vapor was sampled at two points: air aerosols sampling site and residential properties. Field radonometry was performed at the same points.

Air aerosols were sampled with a special air sampler "JAP-50". Production rate of this unit is 50–60 m^3/h. Powered by 220 V. "Petryanov" tissue was used as a filter. Filtering area comprised 250 cm^2. Total volume of filtered air was measured with mechanical volume gauge in m^3. All the air aerosols samples were analyzed by gamma-spectrometric method for determination of volumetric activity of natural and artificial radionuclides. The results of the laboratory measurements are presented Table 24.

Table 24.

Gamma spectrometric measurements of air aerosol samples

№	Sampling point	Volumetric activity, Bq/m^3					
		^{7}Be	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs
1	Sholandyr	$< 9*10^{-4}$	$< 7*10^{-3}$	$< 7*10^{-4}$	$< 2*10^{-3}$	$< 8*10^{-5}$	$< 2*10^{-4}$
2	Akbiik (2010)	$< 9*10^{-4}$	$< 8*10^{-3}$	$< 9*10^{-4}$	$< 1*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
3	Tolegen (2010)	$< 9*10^{-4}$	$< 8*10^{-3}$	$< 9*10^{-4}$	$< 2*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
4	Akshake	$< 9*10^{-4}$	$< 8*10^{-3}$	$<9*10^{-4}$	$<1*10^{-3}$	$<9*10^{-5}$	$< 2*10^{-4}$
5	Tileubek	$< 9*10^{-4}$	$< 7*10^{-3}$	$< 9*10^{-4}$	$<1*10^{-3}$	$< 8*10^{-5}$	$< 2*10^{-4}$

№	Sampling point	Volumetric activity, Bq/m^3					
		^{7}Be	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs
6	Akbiik (2011)	$< 9*10^{-4}$	$< 8*10^{-3}$	$< 7*10^{-4}$	$< 2*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
7	Tolegen (2011)	$< 9*10^{-4}$	$< 7*10^{-3}$	$< 8*10^{-4}$	$< 2*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
8	Sunkar	$< 9*10^{-4}$	$< 7*10^{-3}$	$< 9*10^{-4}$	$< 2*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
9	Kyzyl	$< 9*10^{-4}$	$< 8*10^{-3}$	$< 8*10^{-4}$	$< 2*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
10	Samai	$< 9*10^{-4}$	$< 7*10^{-3}$	$< 9*10^{-4}$	$< 2*10^{-3}$	$< 9*10^{-5}$	$< 2*10^{-4}$
PVA_{pop}, Bq/m^3		$5.0*10^{3}$	$3.1*10^{1}$	$4.9*10^{-3}$	$3.0*10^{-2}$	$2.9*10^{-3}$	$2.7*10^{1}$

The results of the research showed that the volumetric activity of natural and artificial radionuclides in the atmospheric air over the observation period did not exceed the permissible volumetric activity levels for the population according to HS SRRS [28].

Some samples were subjected to radiochemical analysis to determine the volumetric activity of artificial radionuclides ^{90}Sr and $^{239+240}$Pu. The laboratory results are presented Table 25.

Table 25.

Results of radiochemical measurements of air of aerosol samples

№	Sampling point	Bq/m^3	
		^{90}Sr	$^{239+240}$Pu
1	Akbiik	<0.0008	<0.001
2	Tolegen	<0.0008	<0.001
3	Sunkar	<0.0008	<0.001
4	Kyzyl	<0.0008	<0.001
5	Samai	<0.0008	<0.001
PVA_{pop},Bq/m^3		2.7	0.0025

The laboratory studies have found that the content of radionuclides in the air of the study area does not exceed the levels regulated by HS SRRS.

The taken water vapor samples were analyzed by beta-spectrometric method. The specific activity of tritium was recalculated into the volumetric by the psychrometric formula taking into account the humidity and temperature during the sampling. According to the study, the concentration of tritium in all the point does not exceed the permissible volume activity for the category "Population" set by HS SRRS [28].

The study showed that the volumetric activity of natural and artificial radionuclides in air study area is at levels that are below the minimal detectable activity of the measurement tools used. Thus, it is safe to say that at the present time, the concentration of natural and artificial radionuclides does not exceed the volume activity (PVA_{pop}) regulated by HS SRRS for the category "Population" and poses no radiation hazard.

In general, field and laboratory findings agree well with the theoretical assessment of the pollution rate. At that, calculated values were for 1-2 orders of magnitude less than data of the analytic studies.

2.5.3. Radon contents in the AIR of the area studied

To assess radon-hazard in the areas we measured radon emanation, EEVA of ^{222}Rn and ^{220}Rn. Radon equivalent equilibrium volume activity was measured in accordance with instrument manual, as well as criteria for evaluation of the potential radon-hazardous areas [34, 35]. Radon exhalation in the soil air was measured in areas of air aerosol sampling. These measurements are based on the accumulation of radon coming from the soil surface or soil in a container mounted on the surface and sealed from the atmosphere, and then sampling the air from the container to determine radon accumulated with the conversion of values to exhalation values by a formula taking into account the time of accumulation and the size of the container.

The results are shown in Table 26.

Table 26.

Results of field measurements

№	Measurement point	EEVA ^{222}Rn, Bq/m^3	EEVA ^{220}Rn, Bq/m^3	Radon exhalation, mBq / (m^2*s)
1	Sholandyr	18	<8	1680
2	Akbiik	9	<8	1456
3	Tolegen	12	<8	1120
4	Akshake	17	<8	728
5	Tileubek	20	<8	3108
6	Akbiik (2011)	<4	<8	28
7	Tolegen (2011)	7	<8	168
8	Sunkar	5	<8	84
9	Kyzyl	5	<8	56
10	Samai	6	<8	140

The studies found that this area is classified radon-hazardous as radon exhalation significantly exceed 80 mBq/(m^2*s). Volume activity of radon and thoron in the air over the observation period did not exceed the permissible average annual volume activity for the population set by HS SRRS to be 200 Bq/m^3.

Concentrations of natural and artificial radionuclides in air are therefore within the permissible levels. The exclusion are the data for surface radon exhalation density, which are above the regulatory level.

2.5.4. Forecast of changes in radionuclide contamination of air basin

Based on the results, we can conclude that the current levels of radioactive pollution of the air in the study area pose no radiation hazard to the population. Radioactive contamination of the atmosphere can be dangerous to those located directly at the radiation-hazardous objects and only if the air contains large amounts of dust (during dust storms, man-made dusting, etc.). Thus, studies of the artificial radionuclides concentration of at "Experimental field" identified significant excess of allowable levels. This means that it is dangerous to be and more over to exploit active business (that causes dusting) in the vicinity of such facilities. However, transboundary release outside of these areas, and especially beyond the test site is insignificant and not a danger at present or in the future. Because with time the radionuclides

migrate into e soil to a depth then contamination with radionuclides due to wind transport is minimized. Thus, the radiology of the air basin should only get better.

One should note that air pollution with artificial radionuclides above the regulatory levels is only possible in contaminated epicentres of nuclear explosions in case of anthropogenic disturbance of the soil there.

2.6. Vegetation cover conditions

2.6.1. Assessment of natural and artificial radionuclides in vegetation cover on the studied territory

To assess radionuclide contamination of vegetation in the study area we conducted expeditionary operations on coupled sampling of soil and plants to determine specific activity and calculate accumulation factors (AF) of natural (^{40}K, ^{232}Th, ^{226}Ra) and artificial (^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am and ^{60}Co, ^{152}Eu, ^{154}Eu, ^{155}Eu) radionuclides. To do this, in areas with high specific activity of radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in soil established by the area survey on zones of contamination, 10 research platforms (sampling points) were laid: 4 points in 1st zone and 3 points in the 2nd and 3rd zone (Figure 29). The distribution of the sampling points in the study area is satisfied with the results of the study of vegetation cover and the most basic geobotanical contour – ecosystem of denudation-tectonic low mountain, high and low erosive Upland, diluvial-proluvial and alluvial plains.

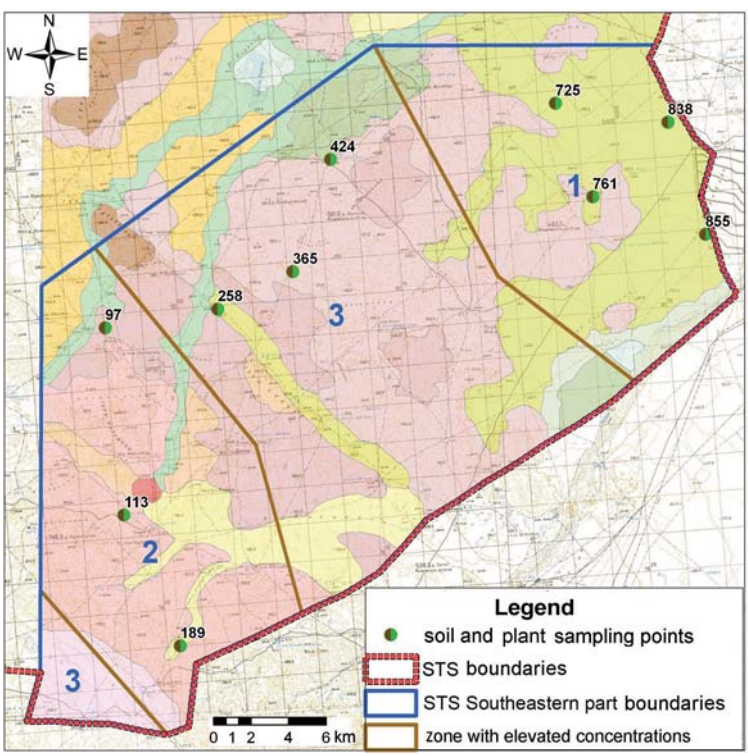


Figure 29. Location of soil and plant sampling points

At each site we took composite samples of soil (using "envelope" (2×1 m) at a depth of 5 cm) and above-ground parts of plants (sampling are ~2 sq. m.) represented by mixed samples of steppe grasses dominated by feather grass *(Stipa capillata, S. sareptana, S. lessingiana)*, fescue *(Festuca valesiaca)* and wormwood *(Artemisia gracileccens, A. frigida)*. Total 10 soil samples and 10 samples of plants were taken.

To estimate the transfer parameters of natural and artificial radionuclides from soil to aerial part of the plant we used one of the most widely used in the world index – accumulation factor (AF) – the ratio of radionuclide content per unit mass of plants and soil, respectively [36].

Content of natural radionuclides in vegetation of the study area

The results of γ-spectrometric analysis to determine the specific activity and accumulation factors (AF) of natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra are shown in Table 27.

Table 27.

Specific activity and AF of ^{40}K, ^{232}Th and ^{226}Ra for the area studied

Point No.	Specific activity, Bq/kg						AF		
	^{40}K		^{232}Th		^{226}Ra		^{40}K	^{232}Th	^{226}Ra
	plant	soil	plant	soil	plant	soil			
725	139.7±4.3	682±21	1.14±0.31	29.5±1.6	0.44±0.08	24.2±0.9	0.20	0.039	0.018
761	180.9±2.8	732±22	1.61±0.13	30.7±1.8	0.93±0.06	31.0±1.1	0.25	0.052	0.030
838	117.0±5.1	692±21	1.38±0.40	29.9±1.8	0.17±0.10	25.0±1.0	0.17	0.046	0.0068
855	213.2±1.6	798±24	0.45±0.06	36.2±2.0	0.27±0.03	33.8±1.1	0.27	0.012	0.0080
97	164.3±2.5	543±34	0.61±0.11	22.7±2.5	0.22±0.05	22.7±1.3	0.30	0.027	0.0097
113	130.4±1.6	509±33	0.40±0.11	21.9±2.5	0.52±0.05	26.6±1.3	0.26	0.018	0.020
189	166.9±2.6	460±31	0.55±0.11	28.0±2.6	0.33±0.05	26.2±1.3	0.36	0.020	0.013
258	90.2±2.5	515±33	0.70±0.15	24.3±2.5	0.30±0.06	47.7±1.7	0.18	0.029	0.0063
365	154.6±3.1	719±36	1.10±0.22	35.9±2.8	0.94±0.09	30.9±1.4	0.22	0.031	0.030
424	389.9±4.7	568±21	<0.38	16.9±1.5	0.50±0.09	28.6±1.1	0.69	<0.023	0.018
AF average							0.29	0.030	0.016

For assessment of natural radionuclides in vegetation we calculated the average specific activity of ^{40}K, ^{232}Th and ^{226}Ra in plant of the study area, which used average AF of these radionuclides and their average specific activity (SA) in soil, established by the results of areal survey (Table 28).

Table 28.

Calculation of natural radionuclide specific activities in plants of the studied area

Average	Natural radionuclides		
	^{40}K	^{232}Th	^{226}Ra
AF	0.29	0.03	0.016
Average SA in soil, Bq/kg	586	28	26
Calculated SA in plants, Bq/kg	170	0.84	0.42

Based on mean specific activities of ^{40}K, ^{232}Th and ^{226}Ra one can say that the highest content in the vegetation of the study area is observed for ^{40}K, as one of the most common natural radionuclides in nature, concentration of ^{232}Th and ^{226}Ra – 2 orders of magnitude lower.

Character of vegetation contamination with artificial radionuclides

To identify the vegetation contamination with artificial radionuclides we conducted tests to determine specific activity of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in the samples of plants and soil, calculated AF of these radionuclides. The obtained specific activities and AF of radionuclides are presented separately for each of the 3 zones of radioactive contamination in Table 29.

The analysis revealed that the maximal specific activities of ^{137}Cs in plants in the study area do not exceed 8 Bq/kg, ^{90}Sr – 6 Bq/kg, $^{239+240}$Pu – 0.2 Bq/kg, ^{241}Am –below the detection limit (<0.17 Bq/kg).

Accumulation parameters of the studied radionuclides vary over a wide range in the next row decreasing: AF ^{90}Sr> AF ^{137}Cs> AF $^{239+240}$Pu. AF of ^{241}Am, due to lack of quantitative specific activity of the radionuclide in the plant, is shown as estimative. Significant differences in the accumulation of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu are observed for the different radioactive contamination zones. The minimal AF of all listed radionuclides is typical for the 1st zone, which is likely due to a lack of available species of radionuclides for plants in soils, caused by specific fallout from radioactive cloud. AF for the 2nd and 3rd zone of radioactive contamination in general is the same.

Additionally we analyzed the plant and soil samples for specific activity of ^{60}Co, ^{152}Eu, ^{154}Eu, ^{155}Eu, calculated AF of these radionuclides (Table 30).

The results showed that the specific activities of ^{60}Co, ^{152}Eu, ^{154}Eu and ^{155}Eu in plants in most cases are below the detection limit (<0.17 Bq/kg). Therefore, a more detailed assessment of vegetation contamination with artificial radionuclides was carried out only for ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am, and for ^{151}Sm and ^{99}Tc, which also have an impact on the study area.

For a more objective assessment of vegetation contamination with artificial radionuclides we calculated an average specific activity ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am, ^{151}Sm and ^{99}Tc in the plants based on data of areal survey to determine these radionuclides in soils of the study area. For this goal we additionally considered quantitative AF of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in the IAEA materials [37] and AF ranges obtained previously for other territories of the STS characterized as the study area by steppe vegetation on light chestnut soils [38, 39]. The table shows the mean values and ranges of AF of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am for some plant groups (Table 31).

Table 29.

Specific activity and AF of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am for the studied area

Z*	Point number	Specific activity, Bq/kg								AF			
		^{137}Cs		^{90}Sr		$^{239+240}$Pu		^{241}Am		^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
		v.**	s.***	v.	s.	v.	s.	v.	s.				
1	725	3.2±0.3	47±1	3.3±0.2	16±1	0.071±0.014	8.5±0.4	<0.15	0.87±0.29	0.068	0.20	0.0084	<0.17
	761	5.8±0.2	131±2	6.01±0.35	55±2	0.17±0.02	32±1	<0.15	2.4±0.4	0.045	0.11	0.0054	<0.063
	838	4.9±0.5	169±2	4.5±0.3	36±1	0.13±0.02	32±1	<0.17	1.6±0.4	0.029	0.12	0.0039	<0.11
	855	4.3±0.1	113±2	4.3±0.4	35±1	0.20±0.03	26±1	<0.15	0.64±0.33	0.038	0.12	0.0075	<0.23
AF average for 1st zone										0.045	0.14	0.0063	<0.14
2	97	5.9±0.2	41±2	1.9±0.3	4.9±0.9	0.19±0.02	11±0.6	<0.15	<0.55	0.14	0.39	0.017	<0.27
	113	7.9±0.2	35±2	3.6±0.3	12±1.0	0.13±0.02	10.6±0.6	<0.15	<0.61	0.23	0.31	0.012	<0.25
	189	7.3±0.3	29±1	3.5±0.3	8.4±1.0	0.081±0.016	3.1±0.3	<0.15	1.2±0.4	0.26	0.42	0.026	<0.13
AF average for 2nd zone										0.21	0.37	0.018	<0.23
3	258	6.3±0.3	48±2	2.8±0.4	9.6±1.0	0.11±0.02	2.2±0.3	<0.15	0.92±0.42	0.13	0.29	0.049	<0.16
	365	7.8±0.3	26±1	2.8±0.3	7.1±0.8	0.059±0.016	1.7±0.2	<0.15	0.92±0.40	0.30	0.39	0.036	<0.16
	424	3.3±0.3	54±2	2.6±0.4	7.3±0.8	нет	3.2±0.3	<0.17	0.94±0.28	0.061	0.36	-	<0.18
AF average for 3rd zone										0.16	0.35	0.043	<0.17
AF average for entire territory studied										0.13	0.27	0.017	<0.17
Note: Z* – radioactive contamination zone, v.** – plant, s.*** – soil													

Table 30.

Specific activity and AF of ^{60}Co, ^{152}Eu, ^{154}Eu and ^{155}Eu for the area under study

Point number	Specific activity, Bq/kg								AF			
	^{60}Co		^{152}Eu		^{154}Eu		^{155}Eu		^{60}Co	^{152}Eu	^{154}Eu	^{155}Eu
	v.*	s.**	v.	s.	v.	s.	v.	s.				
725	<0.29	<0.45	<0.20	0.9±0.3	<1.05	<1.5	<0.23	1.9±0.5	<0.64	<0.22	<0.70	<0.12
838	<0.50	0.57±0.31	<0.19	4.5±0.4	2.6±1.2	<1.7	<0.39	1.2±0.5	<0.88	<0.042	<1.5	<0.36
258	<0.23	1.1±0.6	<0.10	1.6±0.3	1.7±0.7	<3.1	<0.25	<1.1	<0.21	<0.063	<0.56	<0.23
365	<0.19	<0.92	<0.18	0.8±0.3	<0.82	<3.2	0.38±0.15	1.5±0.7	<0.21	<0.23	<0.26	0.25
113	<0.16	<0.80	<0.16	1.2±0.3	<0.65	<2.5	<0.21	<1.0	<0.20	<0.13	<0.26	<0.21
424	<0.27	0.64±0.33	<0.24	<0.4	<1.3	<1.8	<0.33	1.1±0.4	<0.42	<0.60	<0.71	<0.30
761	<0.17	<0.53	<0.13	4.7±0.4	<0.63	3.7±1.3	<0.28	2.1±0.5	<0.32	<0.028	<0.17	<0.13
855	<0.28	<0.50	<0.14	3.4±0.4	<0.33	<2.0	<0.15	1.2±0.5	<0.56	<0.041	<0.17	<0.13
189	<0.28	<0.82	<0.19	1.6±0.3	<0.85	<3.0	0.50±0.17	2.9±0.7	<0.34	<0.12	<0.28	0.17
97	<0.20	<0.81	<0.13	0.6±0.3	<0.57	<2.8	<0.20	1.0±0.6	<0.25	<0.22	<0.20	<0.20
AF mean value									<0.40	<0.17	<0.48	<0.21
Note: v.* – vegetation, s.** – soil												

Table 31.

Ranges of AF of artificial radionuclides for specific groups of plants characteristic for the study area

Plants	AF			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
IAEA (2009 г.)				
Motley grasses	0.1 (n=10) 0.01 – 0.2	0.9 (n=6) 0.3 – 2.0	-	-
Pasture grass	0.4 (n=124) 0.01 – 2.6	1.2 (n=58) 0.4 – 2.6	0.0006 (n=10) 0.00006 – 0.003	0.003 (n=11) 0.005 – 0.02
"Background" Northern Territories of the STS (2008)				
Steppe motley grasses	0.02 (n=14) 0.003 – 0.06	<0.40 (n=4)	0.03 (n=9) 0.01 – 0.1	0.06 (n=3) 0.02 – 0.11
"Background" West Territories of the STS (2009-2010.)				
Steppe motley grasses	0.05 (n=12) 0.01 – 0.1	0.8 (n=3) 0.1 – 1.7	0.04 (n=13) 0.002 – 0.2	<0.20 (n=22)
"Balapan" site (2000-2005)				
Steppe motley grasses	0.34 (n=41) 0.001 – 4.77	0.71 (n=31) 0.02 – 2.30	0.05 (n=30) 0.001 – 0.26	0.29 (n=2) 0.07 – 0.51
"Experimental Field" (2010)				
*Feather (Stipa capillata)	0.01 (n=32) 0.001-0.1	0.1 (n=30) 0.002-0.3	0.01 (n=32) 0.00001-0.04	0.001 (n=32) 0.0001 – 0.01
Note: in the numerator – the arithmetic mean, in brackets – number of cases denominator – range of values "-" – No data available; * – one of the dominant species of the steppe ecosystem				

Average AF of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in this report is deemed to be the values obtained for the 3 zones of radioactive contamination, while the average AF of ^{241}Am, due to lack of quantitative values for the study area, we accepted the values for one of the dominant species of the steppe plants (feather *(Stipa capillata)*) in the territory of "Experimental Field" and pasture grasses based on the IAEA (2009) [39, 37]. No data on AF of ^{151}Sm and ^{99}Tc were found. However, as the closest element to ^{151}Sm by its chemical properties is Pm, and for ^{99}Tc – Mn, we can assume that AF for them will be similar. Thus, the average AF of ^{151}Sm and ^{99}Tc is taken to be AF of Pm and Mn, given in the material on the "north" territory. [38]

Given the accepted AF and average specific activity (SA) of radionuclides in the soil we calculated the average content of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in plants (Table 32).

Table 32.

Calculation of artificial radionuclide specific activity in the plants of the study area

Zone	Average	Artificial radionuclides					
		^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{151}Sm	^{99}Tc
1	AF	0.045	0.14	0.0063	0.002	0.5	5
	Average SA in soil, Bq/kg	43.9	18.9	14.9	0.8	3.5	0.7
	Расчетная УА in plants, Bq/kg	2.0	2.7	0.094	0.0016	1.75	3.5
2	AF	0.21	0.37	0.018	0.002	0.5	5
	Average SA in soil, Bq/kg	30.2	4.2	5.9	0.8	2.4	0.5
	Calculated SA in plants, Bq/kg	6.3	1.6	0.11	0.0016	1.2	2.5

Zone	Average	Artificial radionuclides					
		^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{151}Sm	^{99}Tc
3	AF	0.16	0.35	0.043	0.002	0.5	5
	Average SA in soil, Bq/kg	19.0	3.4	3.7	0.7	1.5	0.3
	Calculated SA in plants, Bq/kg	3.04	1.2	0.16	0.0014	0.75	1.5
Average calculated SA in plants, Bq/kg		3.8	1.8	0.12	0.0015	1.2	2.5
Permissible levels in plants, Bq/kg		74	111	~10*	~10*	~1,000*	~1,000*
Note: * – prospective permissible levels, see below.							

The calculation results obtained do not contradict the general analytical data – average calculated specific activity of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am in plants for each zone of radioactive contamination of the study area is below the content of these radionuclides in plants, selected from areas with elevated levels of soil contamination.

Estinative content of ^{137}Cs and ^{90}Sr in plants does not exceed the maximum permissible levels of radioactive contamination of food plants (^{137}Cs – 74 Bq/kg, ^{90}Sr – 111 Bq/kg), established by the Ministry of Agriculture of the Republic of Kazakhstan (1994) [40].

Concentrations of $^{239+240}$Pu, ^{241}Am, ^{151}Sm and ^{99}Tc in plants are not standardized, however, based on total radiotoxicity of each, it can be assumed that the allowable levels for $^{239+240}$Pu, ^{241}Am will be approximately an order of magnitude smaller, and ^{151}Sm and ^{99}Tc – an order of magnitude more than for ^{90}Sr [28]. This assumes the permissible levels in the plant for all of the radionuclides are well above both average and average maximal for $^{239+240}$Pu and ^{241}Am, of the calculated SA in them.

2.6.2. Character of vegetation contamination with tritium

In order to identify the contamination sources, potentially affecting the southeastern part of the STS (Sarzhal village), the cartographic material and satellite images of the area were analysed. The results of studies of vegetation helped identified areas for further investigation with a particular type of vegetation, characterized by additional moisture, or relatively shallow water – areas of ^{3}H radionuclide contamination of groundwater (shallow water) in streams Baitles and Toktakushuk and possible migration pathways of ^{3}H in south–east vector. Expeditions resulted in 24 research sites (sample points) (Figure 30).

The main objects of study were plants with good ability to accumulate ^{3}H in their above-ground parts [29]. Of hygrophyte with the highest demand for water, and so it is often grown near the surface watercourse – reed (*Phragmites australis*), phreatophytes with deeply penetrating roots that reach the water table and growing in relatively shallow areas of the groundwater – cheegrass (*Achnaterum splendens*), licorice (*Glycyrrhizauralensis*), chingil (*Halimodendronhalodendron*). If none of these species was found, we sampled wild rye *(Leymus angustus)* and thrift *(Limonium gmelinii)* – mesophytes who prefer moderate moisture and growing in areas close to ground water table near surface. In few cases feather *(Stipa sareptana)* and wormwood *(Artemisiafrigida)*.

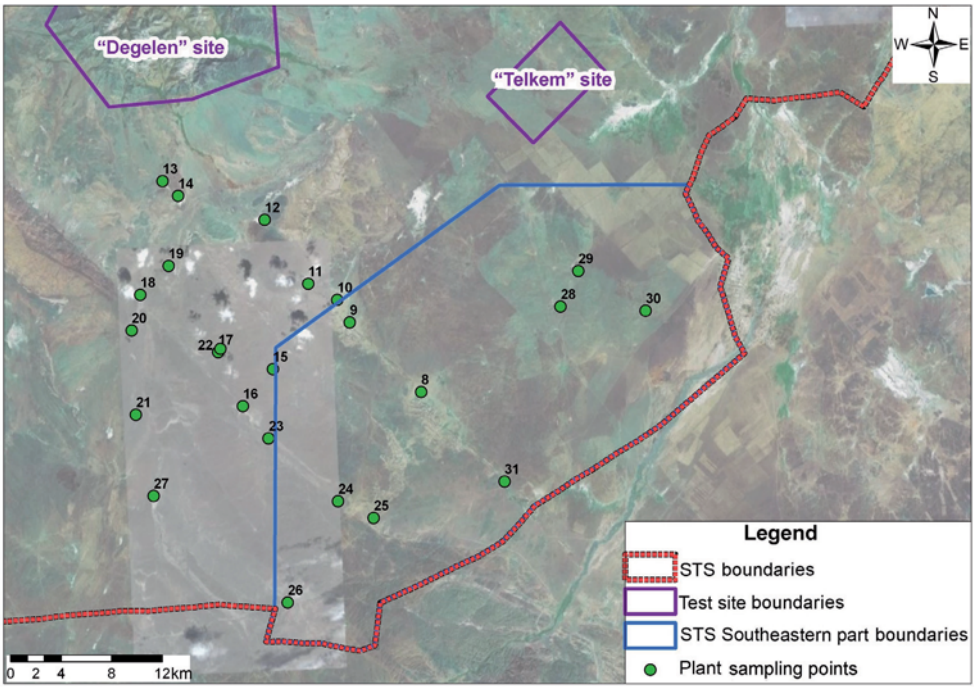


Figure 30. Location of plant sampling points

For more accurate information, on individual research sites several species belonging to different ecological groups were sampled conjugate. Thus, total 70 plant samples were taken. The herbaceous plant test samples are represented by aboveground parts, shrubs and trees – amount of growth for this year. ^{3}H was determined in the free water of plants obtained from the condensate through a special unit, which is a sealed container for loading samples of plants, equipped with a cooled surface and the capacity to collect moisture evaporated from plants.

Specific activity of ^{3}H was measured in prepared samples by liquid scintillation spectrometer TRI-CARB 2900 TR [27].

The data on ^{3}H specific activity in free water of selected plants are presented in Table 33.

Table 33.

Specific activity of ^{3}H in free water of plants in the study area

Sampling point	Plant species	Specific activity of ^{3}H, Bq/kg	Sampling point	Plant species	Specific activity of ^{3}H, Bq/kg
8	Silver chingil	<12	20	jiji grass	20±2
9	jiji grass	<12		wormwood sage	<11
10	jiji grass	<13	21	jiji grass	25±2
	wild rye	<13		Wormwood sareptana	50±5
	Ural licorice	<13		Ural licorice	15±1

Sampling point	Plant species	Specific activity of ^{3}H, Bq/kg	Sampling point	Plant species	Specific activity of ^{3}H, Bq/kg
11	jiji grass	550±50	22	Wormwood sareptana	15±1
	wild rye	150±10		jiji grass	<12
12	wild rye	25±2		Ural licorice	<11
13	Silver chingil	400±40	23	jiji grass	<11
	jiji grass	25±2		narrow leaved wild rye	40±4
14	wild rye	40±4		wormwood sage	20±2
	jiji grass	200±20		Limonium Gmelini	35±3
15	jiji grass	<12	24	jiji grass	15±1
16	jiji grass	1500±100	25	jiji grass	<11
	wild rye	450±40		wild rye	15±1
17	jiji grass	45±4	26	jiji grass	20±2
	narrow leaved wild rye	300±30		wild rye	<11
18	reed	500±50	27	jiji grass	<11
	wild rye	250±20	28	wormwood sage	<12
	jiji grass	350±30		jiji grass	<13
19	jiji grass	15±1	29	jiji grass	<14
	Wormwood sareptana	45±4	30	Silver chingil	<13
	wild rye	<11	31	jiji grass	<13

It was found that ^{3}H specific activity in the vegetation of study area ranges from <11 to 550 Bq/kg, in one case – reaches 1,500 Bq/kg at point 16.

Based on the maximal specific activity of ^{3}H in plants (for each site) ^{3}H distribution layout in vegetation of the study area was constructed (Figure 31).

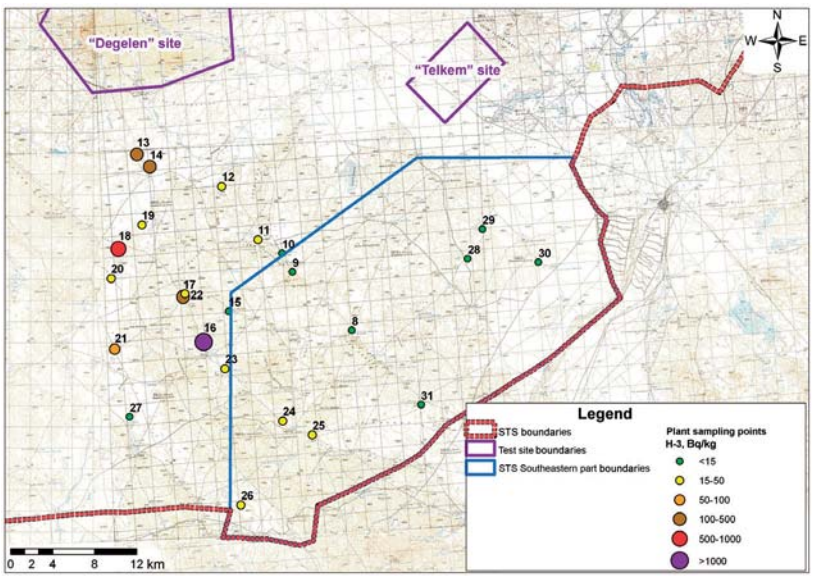


Figure 31. Distribution of ^{3}H in free water of plants

Elevated concentrations of ^{3}H confined to Baitles and Toktakushuk streams impact zone and that, in turn, are places where ^{3}H contaminated groundwater and surface water go beyond "Degelen" site. Specific activity of ^{3}H in vegetation directly on the territory in the southeastern part of the STS at this point in most cases is below the detection limit (<15 Bq/kg), the quantitative values (up to 50 Bq/kg) are found only in the south-west. The level of intervention at intake of this radionuclide with water, according to HS SRRS is 7.6 kBq/kg [28].

2.6.3. Assessment of quality of the vegetation cover and prognosis of changes in its radionuclide contamination

The study area covers lowland, hummocky-flat plains and desert steppes. Vegetation cover pertains to desert sagebrush- sod grass steppes on light chestnut soils. Content of artificial radionuclide ^{137}Cs in plants does not exceed 10 %, ^{90}Sr – 5 % of the maximum permissible levels [40]. $^{239+240}Pu$ concentration in plants is less than 3 %, and ^{241}Am, ^{151}Sm and ^{99}Tc – less than 1 % of the estimated permissible levels. No abnormal specific activities of natural radionuclides in plants in the area were identified.

The contamination level of vegetation with such radionuclides as ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am, above all, depends on the ability of the plants to accumulate the radionuclides and the accessibility of the latter, determined by soil characteristics. Newly injected radionuclides in the first period in the soil may be more available for accumulation by plants than in later periods when equilibrium state of radionuclides is achieved. The intensity of this process depends on the physicochemical properties of radionuclides. So, for ^{137}Cs it is typical to decrease in accumulation by plants over time, whereas ^{90}Sr's mobility in the soil-plant system changes slowly [41]. The above facts allow us to make a prediction mostly about possible reduction in concentration of ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am in the vegetation cover in the future than its possible rise.

More complicated situation can be noted for vegetation contamination with ^{3}H. Although ^{3}H specific activity in the vegetation of the study area in most cases is below the detection limit (<15 Bq/kg), the presence of quantitative values (up to 50 Bq/kg) in the south-west and the increase of its concentration in the vicinity (in Baitles and Toktakushuk streams impact zone) cannot be ignored. Ability of ^{3}H to migrate with groundwater may in the future cause expansion of the area with the specific activity quantitative values of the latter, and a general increase of its content in the vegetation of the study area. However it is one of the most dangerous scenarios of possible developments. At the moment, ^{3}H specific activity numerical values (up to 50 Bq/kg) in the vegetation of the study area are found only at its extreme south-western sector and are well below the intervention level at intake this radionuclide with water, which, according to HS SRRS is 7.6 kBq/kg.

Thus, the vegetation in the study area in terms of contamination with natural (^{40}K, ^{232}Th, ^{226}Ra) and artificial (^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am, and ^{60}Co, ^{152}Eu, ^{154}Eu, ^{155}Eu) radionuclides neither today nor in the future pose any danger to the public and can be considered suitable for certain types of economic activity. In turn, with respect to ^{3}H contamination it is recommended in the south-western part of the study area to conduct surveillance monitoring of its concentration in crop products, in particular, plant feed (hay) where it is harvested.

2.7. Assessment of the state of wild animals in terms of radionuclide contamination. prognosis of tendencies in radionuclide contamination of animals

Assessment of ^{3}H in the body of commercial waterfowl

The main radionuclide posing a risk in the study area is ^{3}H due to its mobility in the groundwater from "Degelen" site far beyond of its limits (Section 4.4). Therefore, during these studies in the "south-east" STS five water birds that live in the lakes within the study area, which are the hunting targets and can be used in food were analysed for radionuclides. Of these three individuals – green-winged teal, two – common coot. The results are presented in Table 34.

Table 34.

Distribution of ^{3}H in waterfowls – hunting targets

№	Species	Specific activity of ^{3}H, Bq/kg
1	common coot	<20
2	common coot	40±20
3	green-winged teal green	<20
4	green-winged teal green	<20
5	green-winged teal green	<20

It is clear from these results that the content of ^{3}H in most samples did not exceed the lower limits of the measurement tools. Specific activity of ^{3}H in food products is not regulated, but for the sake of comparison, we got ^{3}H specific activity in free water of the muscle tissue (40±20 Bq/kg) to be much below the IL for drinking water which is 7,600 Bq/kg [28].

Prediction of radionuclide intake by some commercial species of wild animals

Having no data on the concentration of radionuclides in the body of the wild animals living in the study area necessitated an estimative forecast of radionuclides in meat of commercial animals based on available data on the concentrations of radionuclides in environmental media (soil, plants).

Wild animals that are of commercial use

Of the 46 species of mammals living in the study area, 11 are targets of amateur hunting, 9 of which are the objects of commercial hunting (Table 35). Of the 147 species of birds 22 species are objects of amateur hunting, 18 species – commercial hunting and 28 species are used for other business purposes (except for hunting). 3 species of reptiles out of 7 are used for other purposes (except for hunting) [42].

Table 35.

Mammals that are of commercial use

Order	Hunting targets		
	Species	commercial hunting	Amateur (sports) hunting
Rapacious	corsac fox (*Vulpes corsac*)	+	+
	fox (*V. vulpes*)	+	+
	steppe polecat (*M. eversmani*)	+	+
	badger (*Meles meles*)	+	+
Cloven-footed	Siberian Roe Deer (*Capreoluspygargus*)		+
	saiga (*Saigatatarica*)	+	+
	moose (*Alces alces*)		+
Rodents	bobak marmot (*Marmota bobak*)	+	+
	water rat (*Ondatra zibeticus*)	+	+
Double-toothed rodents	brown hare (*Lepus europeus*)	+	+
	blue hare (*L. timidis*)	+	+

Assessment of radionuclide intake into some commercial species of wild animals in the case of habitat in the study area

Since there are no published data on transfer factors (TF) of radionuclides into wild animals it was decided to use maximal TF, found in the literature and adopted in the preparation of the study materials for prediction of radionuclide intake for farm animals (Table 48), and TF, resulted from the experiments at the STS.

As a result, TF used is ^{137}Cs – $2.3*10^{-1}$, ^{90}Sr – $1.1*10^{-4}$ (maximal TF resulted from the experiment with farm animals at the STS (Table 48)). For $^{239+240}$Pu and ^{241}Am we accepted $6.0*10^{-5}$ and $5*10^{-4}$, respectively (small cattle meat). These maximal TF are derived for cloven-hoofed farm livestock, therefore we assessed the possible concentration of radionuclides in wild cloven-hoofed animals – saiga, Siberian roedeer and moose.

Based on the data on the estimated concentrations in vegetable foods, resulted from calculating the average values of radionuclides in the soil of the selected zone 1 (Table 41), and data on the daily consumption of pasture forage, there was calculated data on possible annual and daily intake of radionuclides in the body of wild animals in case they are fed in the study area. The calculation results are presented in Table 36.

Table 36.

Calculation results of possible radionuclide uptake by the wild animals in the studied area

Animal species	Average weight of animal unit, kg	Consumption of pasture forage (dry weight), kg	Average daily intake of radionuclides by one animal, Bq			
			^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Moose	350-400	18	87.3	78.1	3.9	0.02
Saiga	50-60	3.5	77.6	69.4	3.4	0.02
Siberian roedeer	50-60	3	12.1	10.5	0.5	0.003

Based on the data on the average daily intake of radionuclides in the body of animals (Table 36) and those selected to calculate TF we assessed the possible concentrations of radionuclides in the body of wild animals. Table 37 shows the results of the predicted radionuclide concentrations in meat of wild animals and permissible of radionuclide contents in food, according to HS SRRS [43]. Content of $^{239+240}$Pu and ^{241}Am in food is not standardized, however, in view of that in HS SRRS (Annex 3), the limit of annual intake with food for people is an order of magnitude smaller than the same value for ^{90}Sr ($^{239+240}$Pu –2.4*10^{3} Bq/year, ^{241}Am – 2.7*10^{3} Bq/year, ^{90}Sr – 1.3*10^{4} Bq/year) and in view of their high radiotoxicity, we can assume that the allowable levels for them will be much smaller than for ^{90}Sr [28]. Permissible levels for $^{239+240}$Pu and ^{241}Am are given in Table 37 based on this this calculation.

Table 37.

Predicted specific activity of radionuclides in meat of wild animals

Product type	Predicted concentrations, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Meat (moose)	2.0*10^{-1} (300)	8.6*10^{-3} (100)	2.3*10^{-4} (10)	1.0*10^{-5} (10)
Meat (saiga)	1.8*10^{-1} (300)	7.6*10^{-3}(100)	2.0*10^{-4} (10)	1.0*10^{-5} (10)
Meat (Siberian roedeer)	2.78*10^{-2} (300)	1.16*10^{-3} (100)	2.7*10^{-5} (10)	3.3*10^{-7}(10)

The resulting predicted specific activities in the meat of game animals did not exceed the concentrations of radionuclides in food, according to HS SRRS [43].

2.8. The oretical assessment of contamination levels for crop products based on the experimenal data on soil contamination

To estimate the contamination levels of agricultural crops one should have data on the radionuclide concentrations in soils of the studied area and radionuclide transfer factors (TF) into different types of crop products:

$$TF = \frac{C_{plant.}}{C_{soil}},$$

where:
TF – transfer factor;
$C_{plant.}$ – radionuclide concentration in vegetation (Bq/kg);
C_{soil} – radionuclide concentration in soil.

Choice of transfer coefficient based on literature data

In 2009 the IAEA published the report "Quantification of radionuclide transfer into terrestrial and freshwater environments for radiological assessments" containing the factors of radionuclide transfer into crop products (Table 38) [37].

Table 38.

TF of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu into crop products

Product type	TF			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops	$4.3*10^{-2}$	$1.6*10^{-1}$	$4.7*10^{-5}$	$1.7*10^{-2}$
Maize	$2.3*10^{-2}$	$4.0*10^{-1}$	$3.0*10^{-6}$	$9.6*10^{-4}$
Leaf vegetables	$1.8*10^{-1}$	2.0	$2.8*10^{-4}$	$2.4*10^{-4}$
Vegetables (tomatoes, cucumbers)	$9.4*10^{-2}$	1.5	$8.5*10^{-5}$	$7.9*10^{-4}$
Legumes (seeds)	$4.3*10^{-2}$	1.5	$6.7*10^{-5}$	$4.8*10^{-4}$
Potatoes (tubers)	$4.6*10^{-2}$	$2.0*10^{-1}$	$9.9*10^{-4}$	$9.1*10^{-4}$
Tuberous roots (roots)	$5.3*10^{-2}$	1.3	$1.7*10^{-3}$	$8.6*10^{-4}$

In order to estimate factors of ^{137}Cs transfer into crop products the authors generalized and analyzed the data for 7 Russian oblasts for 1987-1993. The data analysis showed that for the same type of soil the accumulation of radionuclides depended on soil granulometric composition, and the values of radionuclide accumulation differed by a factor of 1.5-7 [44]. Maximal values of ^{137}Cs TF for light and medium loamy soils are given in Table 39.

Table 39.

TF of ^{137}Cs into crop products in light and medium-loamy soils

Product type	TF of ^{137}Cs	Product type	TF of ^{137}Cs
Winter rye, grain	$1.1*10^{-1}$	Maize, vegetative mass	$2.9*10^{-1}$
Winter wheat, grain	$1.1*10^{-1}$	Potatoes, roots	$1.3*10^{-1}$
Barley, grain	$1.7*10^{-1}$	Beet (roots)	$1.3*10^{-1}$
Oats, grain	$2.1*10^{-1}$		

No research on migration of radionuclides in agricultural crop products in the STS has been conducted.

Accepted TFs

Given that no studies on migration of radionuclides from the soil in grain crops and vegetable crops have been done in the STS, maximal TFs, found in the literature (Table 40), have been accepted.

Table 40.

TF of ^{137}Cs, ^{90}Sr и $^{239+240}$Pu in crop products accepted for forecasts

Product type	TF			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops				
Rye	$1.1*10^{-1}$	$1.6*10^{-1}$	$4.7*10^{-5}$	$1.7*10^{-2}$
Wheat	$1.1*10^{-1}$	$1.6*10^{-1}$	$4.7*10^{-5}$	$1.7*10^{-2}$
Barley	$1.7*10^{-1}$	$1.6*10^{-1}$	$4.7*10^{-5}$	$1.7*10^{-2}$
Oats	$2.1*10^{-1}$	$1.6*10^{-1}$	$4.7*10^{-5}$	$1.7*10^{-2}$
Fodder crop				
Maize	$2.9*10^{-1}$	$4.0*10^{-1}$	$3.0*10^{-6}$	$2.9*10^{-1}$

Product type	TF			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Leaf vegetables				
Cabbage, spinach, celery leaves, lettuce	$1.8*10^{-1}$	2.0	$2.8*10^{-4}$	$2.4*10^{-4}$
Legumes				
Beans, peas	$4.3*10^{-2}$	1.5	$6.7*10^{-5}$	$4.8*10^{-4}$
Fruited vegetables				
Tomatoes, cucumbers, paprika, aubergine	$9.4*10^{-2}$	1.5	$8.5*10^{-5}$	$7.9*10^{-4}$
Tuberous root				
Potatoes	$1.3*10^{-1}$	$2.0*10^{-1}$	$9.9*10^{-4}$	$9.1*10^{-4}$
Beet and carrot (roots)	$1.3*10^{-1}$	1.3	$1.7*10^{-3}$	$8.6*10^{-4}$

2.8.1. Assessment of radionuclide concentration in crop products

In order to estimate contamination of crop products the authors used the data on average radionuclide concentration in soils of the area under investigation and factors of radionuclide transfer into different types of crops accepted based on the analysis of literature data and the results of studies on the STS territory (Table 40). During the preparation of the comprehensive survey materials, based on the study of a large array of radioanalytical data the authors have taken the average concentrations of radionuclides in the soil of the study area (0-5 cm layer). These values were used to calculate the content of radionuclides in the steppe grasses. Based on the fact that the adopted transfer factors for the calculation of radionuclides in garden products were obtained for the 0-20 cm soil layer [37], the specific activity of radionuclides in the soil layer 0-20 cm was calculated. The calculation was made based on the average concentration of radionuclides in soils of the study area (0-5 cm layer) and on the basis of data on the distribution of radionuclides in soils of the territories cited above (Table 9).

For the distribution of radionuclides ^{137}Cs and ^{241}Am the authors adopted the average percentage distribution of radionuclides in soil layers, calculated based on the data from ten soil profiles, for radionuclides ^{90}Sr and $^{239+240}$Pu from four soil profiles. The average distribution of the radionuclide in layers 0-5 cm, 5-10 cm, 10-15 cm and 15-20 were: for ^{137}Cs – 82.1%, 6.9%, 8.5% and 2.5% respectively; for $^{239+240}$Pu – 93.5%, 2.6%, 2.3% and 1.6% respectively; for ^{241}Am – 59.8%, 12.8%, 13.8% and 13.6% respectively; for ^{90}Sr – 62.9%, 15.9%, 14.3% и 6.9% respectively.Since the areal studies on the southeastern STS marked out 3 zones of radiation parameters the average specific activity of the soil (0-20 cm layer) was calculated for each zone (Table 41).

Table 41.

Average specific activity of radionuclides in the soil layer of 0-20 cm for each marked out area of radionuclide contamination

Zone	Average specific activity of radionuclides in the 0-20 cm soil layer, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
1	13.3	7.5	3.9	0.33
2	9.2	1.7	1.6	0.33
3	5.8	0.9	0.9	0.29

The calculated values of radionuclide contents in crop products were obtained for the dry mass of plant products, so to convert them to a wet mass, data on the percentage of dry mass in plants listed in the IAEA recommendations [37].

Prediction of radionuclide concentrations were calculated using the formula:

$$C_{forecast} = C_{soil} \times TF \times \frac{K_{\%}}{100},$$

where

$C_{forecast}$ – concentrations forecasted (Bq/kg);

C_{soil} – average concentration of radionucledes in soil;

TF – transfer factor;

$K_{\%}$ – percentage of dry matter in total mass of plant.

Table 42, Table 43, Table 44 show the results of the forecasted concentrations in plant products origin (wet weight), in case they are produced in the study area and permissible radionuclides concentrations in food are consistent with HS SRRS (Annex 5) [43]. Permissible levels for $^{239+240}$Pu and ^{241}Am in Tables are calculated as in paragraph 42-44.

Table 42.

Forecasted radionuclide concentration in crop products (per wet weight) case produced in the study area (calculated based on the average specific activity of radionuclides in the soil of the zone 1)

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops				
Rye	1.3 (70)	1 (40)	$1.6*10^{-4}$ (4.0)	$4.9*10^{-3}$ (4.0)
Wheat	1.3 (70)	1.1 (40)	$1.6*10^{-4}$ (4.0)	$5.0*10^{-3}$ (4.0)
Barley	2.0 (70)	1.0 (40)	$1.6*10^{-4}$ (4.0)	$4.9*10^{-3}$ (4.0)
Oats	2.4 (70)	1.0 (40)	$1.6*10^{-4}$ (4.0)	$4.9*10^{-3}$ (4.0)
Fodder crops				
Maize	3.3 (70)	2.6 (40)	$1.0*10^{-5}$ (4.0)	$8.2*10^{-2}$ (4.0)
Leaf vegetables				
Cabbage	$2.9*10^{-1}$ (120)	1.8 (40)	$1.3*10^{-4}$ (4.0)	$9.6*10^{-6}$ (4.0)
Spinach	$1.9*10^{-1}$ (120)	1.2 (40)	$8.8*10^{-5}$ (4.0)	$6.4*10^{-6}$ (4.0)
Celery leaves, lettuce	$1.4*10^{-1}$ (120)	$9.0*10^{-1}$ (40)	$6.6*10^{-5}$ (4.0)	$4.8*10^{-6}$ (4.0)
Legumes				
Beans. peas	$4.9*10^{-1}$ (50)	9.6 (60)	$2.2*10^{-4}$ (6.0)	$1.4*10^{-4}$ (6.0)
Fruited vegetables				
Tomatoes, paprika, aubergine	$7.5*10^{-2}$ (120)	$6.8*10^{-1}$ (40)	$2.0*10^{-5}$ (4.0)	$1.6*10^{-5}$ (4.0)
Cucumbers	$6.3*10^{-2}$ (120)	$5.6*10^{-1}$ (40)	$1.7*10^{-5}$ (4.0)	$1.3*10^{-5}$ (4.0)
Tuberous roots (roots)				
Potatoes	$3.6*10^{-1}$ (120)	$3.2*10^{-1}$ (40)	$8.2*10^{-4}$ (4.0)	$6.4*10^{-5}$ (4.0)
Beets (roots)	$2.8*10^{-1}$ (120)	1.6 (40)	$1.1*10^{-3}$ (4.0)	$4.6*10^{-5}$ (4.0)
Carrot (roots)	$2.4*10^{-1}$ (120)	1.4 (40)	$9.4*10^{-4}$ (4.0)	$4.0*10^{-5}$ (4.0)
*Note: maximal permissible concentrations for fodder crops (grass, hay) were established by the Ministry of Agriculture of the Republic of Kazakhstan (^{137}Cs – 74 Bq/kg, ^{90}Sr –111 Bq/kg) [39]				

Table 43.

Forecasted radionuclide concentration in crop products (per wet weight) produced in the study area (calculated based on the average specific activity of radionuclides in the soil of the zone 2)

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops				
Rye	$8.8*10^{-1}$ (70)	$2.3*10^{-1}$ (40)	$6.4*10^{-5}$ (4.0)	$4.9*10^{-3}$ (4.0)
Wheat	$8.9*10^{-1}$ (70)	$2.4*10^{-1}$ (40)	$6.4*10^{-5}$ (4.0)	$5.0*10^{-3}$ (4.0)
Barley	1.4 (70)	$2.3*10^{-1}$ (40)	$6.4*10^{-5}$ (4.0)	$4.9*10^{-3}$ (4.0)
Oats	1.7 (70)	$2.3*10^{-1}$ (40)	$6.4*10^{-5}$ (4.0)	$4.9*10^{-3}$ (4.0)
Fodder crops				
Maize	2.3 (70)	$5.7*10^{-1}$ (40)	$4.0*10^{-6}$ (4.0)	$8.2*10^{-2}$ (4.0)
Leaf vegetables				
Cabbage	$2.0*10^{-1}$ (120)	$4.0*10^{-1}$ (40)	$5.2*10^{-5}$ (4.0)	$9.6*10^{-6}$ (4.0)
Spinach	$1.3*10^{-1}$ (120)	$2.7*10^{-1}$ (40)	$3.5*10^{-5}$ (4.0)	$6.4*10^{-6}$ (4.0)
Celery leaves, lettuce	$9.9*10^{-2}$ (120)	$2.0*10^{-1}$ (40)	$2.6*10^{-5}$ (4.0)	$4.8*10^{-6}$ (4.0)
Legumes				
Beans. peas	$3.4*10^{-1}$ (50)	2.1 (60)	$8.9*10^{-5}$ (6.0)	$1.4*10^{-4}$ (6.0)
Fruited vegetables				
Tomatoes, paprika, aubergine	$5.2*10^{-2}$ (120)	$1.5*10^{-1}$ (40)	$7.9*10^{-6}$ (4.0)	$1.6*10^{-5}$ (4.0)
Cucumbers	$4.3*10^{-2}$ (120)	$1.3*10^{-1}$ (40)	$6.6*10^{-6}$ (4.0)	$1.3*10^{-5}$ (4.0)
Tuberous roots (roots)				
Potatoes	$2.5*10^{-1}$ (120)	$7.0*10^{-2}$ (40)	$3.2*10^{-4}$ (4.0)	$6.4*10^{-5}$ (4.0)
Beets (roots)	$1.9*10^{-1}$ (120)	$3.5*10^{-1}$ (40)	$4.2*10^{-4}$ (4.0)	$4.6*10^{-5}$ (4.0)
Carrot (roots)	$1.7*10^{-1}$ (120)	$3.0*10^{-1}$ (40)	$3.7*10^{-4}$ (4.0)	$4.0*10^{-5}$ (4.0)
*Note: maximal permissible concentrations for fodder crops (grass, hay) were established by the Ministry of Agriculture of the Republic of Kazakhstan (^{137}Cs – 74 Bq/kg, ^{90}Sr –111 Bq/kg) [39]				

Table 44.

Forecasted radionuclide concentration in crop products (per wet weight) produced in the study area (calculated based on the average specific activity of radionuclides in the soil of the zone 3)

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops				
Rye	$5.5*10^{-1}$ (70)	$1.3*10^{-1}$ (40)	$3.9*10^{-5}$ (4.0)	$4.3*10^{-3}$ (4.0)
Wheat	$5.6*10^{-1}$ (70)	$1.3*10^{-1}$ (40)	$4.0*10^{-5}$ (4.0)	$4.4*10^{-3}$ (4.0)
Barley	$8.6*10^{-1}$ (70)	$1.3*10^{-1}$ (40)	$3.9*10^{-5}$ (4.0)	$4.3*10^{-3}$ (4.0)
Oats	1.1 (70)	$1.3*10^{-1}$ (40)	$3.9*10^{-5}$ (4.0)	$4.3*10^{-3}$ (4.0)
Fodder crops				
Maize	1.4 (70)	$3.1*10^{-1}$ (40)	$2.5*10^{-6}$ (4.0)	$7.2*10^{-2}$ (4.0)
Leaf vegetables				
Cabbage	$1.2*10^{-1}$ (120)	$2.2*10^{-1}$ (40)	$3.2*10^{-5}$ (4.0)	$8.4*10^{-6}$ (4.0)
Spinach	$8.3*10^{-2}$ (120)	$1.5*10^{-1}$ (40)	$2.2*10^{-5}$ (4.0)	$5.6*10^{-6}$ (4.0)

Product type	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Celery leaves, lettuce	$6.2*10^{-2}$ (120)	$1.1*10^{-1}$ (40)	$1.6*10^{-5}$ (4.0)	$4.2*10^{-6}$ (4.0)
Legumes				
Beans. peas	$2.1*10^{-1}$ (50)	1.2 (60)	$5.5*10^{-5}$ (6.0)	$1.2*10^{-4}$ (6.0)
Fruited vegetables				
Tomatoes, paprika, aubergine	$3.3*10^{-2}$ (120)	$8.2*10^{-2}$ (40)	$4.9*10^{-6}$ (4.0)	$1.4*10^{-5}$ (4.0)
Cucumbers	$2.7*10^{-2}$ (120)	$6.8*10^{-2}$ (40)	$4.1*10^{-6}$ (4.0)	$1.2*10^{-5}$ (4.0)
Tuberous roots (roots)				
Potatoes	$1.6*10^{-1}$ (120)	$3.8*10^{-2}$ (40)	$2.0*10^{-4}$ (4.0)	$5.6*10^{-5}$ (4.0)
Beets (roots)	$1.2*10^{-1}$ (120)	$1.9*10^{-1}$ (40)	$2.6*10^{-4}$ (4.0)	$4.0*10^{-5}$ (4.0)
Carrot (roots)	$1.1*10^{-1}$ (120)	$1.7*10^{-1}$ (40)	$2.3*10^{-4}$ (4.0)	$3.5*10^{-5}$ (4.0)
*Note: maximal permissible concentrations for fodder crops (grass, hay) were established by the Ministry of Agriculture of the Republic of Kazakhstan (^{137}Cs – 74 Bq/kg, ^{90}Sr –111 Bq/kg) [39]				

The results of investigations showed that even if crops are grown on the areas with maximal radionuclide concentrations their concentration in crop products will not exceed maximal permissible concentration in food products.

2.8.2. The oretical assessment of contamination levels for livestock products

To estimate the radionuclide content in animal products, as in crop products, we used transfer factors (ratio of the concentration of radionuclides in animal products to daily intake with diet).

Choice of transfer factors based on literature data

The contamination of livestock products can be calculated based on the fodder contamination using transfer factors taken from the IAEA reference book "On the values of parameters used to calculate migration of radionuclides in the environments of middle latitudes" published in 1994 (Table 45) [45].

Table 45.

TF of ^{137}Cs and ^{90}Sr in livestock products [45]

Product type	TF	
	^{137}Cs	^{90}Sr
Black cattle		
Milk	$7.9*10^{-3}$	$2.8*10^{-3}$
Meat (beef)	$5.1*10^{-2}$	$8.0*10^{-3}$
Sheep		
Milk	$5.8*10^{-2}$	$5.6*10^{-2}$
Meat (mutton)	$4.9*10^{-1}$	$3.3*10^{-1}$
Goat		
Milk	$1.0*10^{-1}$	$2.8*10^{-2}$
Meat	$2.3*10^{-1}$	$2.8*10^{-3}$
Poultry		
Meat	12.0	$8.0*10^{-2}$
Eggs	$4.5*10^{-1}$	$1.8*10^{-1}$

The IAEA documents published in 2009 [37] contain factors for radionuclide transfer into livestock products (Table 46).

Table 46.

TF of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in livestock products [37]

Product type	TF			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Black cattle				
Milk	$6.1*10^{-3}$	$1.5*10^{-3}$	$1.0*10^{-5}$	$4.2*10^{-7}$
Meat (beef)	$3.0*10^{-2}$	$2.1*10^{-3}$	$6.0*10^{-5}$	$5.0*10^{-4}$
Sheep				
Milk	$7.7*10^{-2}$	$3.0*10^{-2}$	$1.0*10^{-4}$	-
Meat (mutton)	$2.7*10^{-1}$	$1.7*10^{-4}$	$5.3*10^{-5}$	$1.1*10^{-4}$
Goat				
Milk	$1.3*10^{-1}$	$2.1*10^{-2}$	-	$6.9*10^{-6}$
Meat	$4.8*10^{-1}$	$3.0*10^{-3}$	-	-
Poultry				
Meat	3.0	$2.3*10^{-2}$	-	-
Eggs	$4.3*10^{-3}$	$8.8*10^{-1}$	-	-

The Republic of Belarus having wide experience in farming on radioactively contaminated areas issued a guide-book on agroindustrial business in the conditions of radioactive pollution which gives the transfer factors of ^{137}Cs and ^{90}Sr from fodder to the farm products obtained by the Byelorussian Institute of Radiology (Table 47) [46]. These factors are recommended to be used to calculate radionuclide concentration in animal products in the Russian Federation [47].

Table 47.

TFs of ^{137}Cs and ^{90}Sr in livestock products (Byelorussian Institute of Radiology) [46, 47]

Product	TF	
	^{137}Cs	^{90}Sr
Black cattle		
milk	$7.4*10^{-3}$	$1.4*10^{-3}$
meat (beef)	$4.0*10^{-2}$	$4.0*10^{-4}$
Sheep		
meat (mutton)	$1.5*10^{-1}$	$1.0*10^{-3}$
Poultry		
meat	4.5	$2.0*10^{-3}$
eggs	$3.5*10^{-2}$	$3.2*10^{-2}$

The English authors showed that for sheep the factor of ^{137}Cs transfer from the contaminated fodder into muscles was $5.7*10^{-1}$, into kidneys – $5.0*10^{-1}$, and into lever – $3.3*10^{-1}$ [48]. The authors from the Czech Republic determined that the factor of ^{137}Cs transfer in the fodder-milk chain was equal to $4.8*10^{-3}$, and for ^{90}Sr it was $2.4*10^{-3}$. In the fodder-beef chain the factors were $2.1*10^{-3}$ and $6.9*10^{-3}$, respectively [49]. The contamination of wet hay on natural grounds (England) of 550 Bq/kg gave the factor of ^{137}Cs transfer to the beef equal to $2.3*10^{-2}$, and the transfer factor to milk was $1.1*10^{-2}$ [50]. In 1977-1986,

in Great Britain the factor of ^{137}Cs transfer from fodder to milk for livestock with pasture holding was equal to $4.0*10^{-3}$, and for ^{90}Sr – $1.0*10^{-3}$[51]. In Great Britain the factor of ^{137}Cs transfer from global fallouts to milk from different types of fodder was estimated as follows: from hay – $2.0*10^{-3}$ and from green mass – $4.0*10^{-3}$. The measurements for green mass after Chernobyl fallouts gave $1.4*10^{-2}$ [52].

Choice of transfer factors based on STS studies

In order to obtain the transfer factors into livestock products on the STS territory the scientists carried out field scale experiments with farm animals. As experimental animals the two-year-old sheep of Kazakh coarse-haired fat-tail (Edilbay) breed were chosen. In the first case the animals grazed in the conditions of radioactive contamination, in the second – the animals were fed in with radioactive diet at stable keeping [53].

As the experimental site it was decided to choose a radioactively contaminated ecosystem of the waterway of tunnel No. 176 located in on Delegen site. The animals were brought from the farms located in the area not subjected to radioactive contamination (Maysky District, Pavlodar oblast).

In order to estimate the intake of radionuclides in the experimental animals the daily ration of the animals (vegetation, water) and radionuclide concentration in it were controlled. At the end of the pasturing period the animals were slaughtered and the samples of tissues (muscle, bone and skin) and organs (heart, lever, lungs, kidneys) were taken for radionuclide analyses.

Recommended transfer factors based on the experimental results. The data on average daily uptake of radionuclides into organisms of animals and their concentration in tissues and organs were used to calculate factors of radionuclide transfer (TF) from ration into tissues and organs of livestock animals. The factors obtained from grazed animals and those kep at stable keeping are approximate [533]. The maximal transfer factors (TF) are given in Table 48.

Table 48.

Maximal transfer factors of ^{137}Cs and ^{90}Sr into sheep's tissues and organs obtained in the experiment on the STS

Organ (tissue) type	TF		
	^{137}Cs	^{90}Sr	$^{239+240}Pu$
Meat	$2.3*10^{-1}$	$1.1*10^{-4}$	$2.0*10^{-5}$
Heart	$1.2*10^{-1}$	$2.0*10^{-4}$	$5.0*10^{-5}$
Lever	$1.2*10^{-1}$	$1.1*10^{-4}$	$1.4*10^{-3}$
Kidneys	$1.5*10^{-1}$	$2.4*10^{-4}$	$2.1*10^{-4}$
Lungs	$9.8*10^{-1}$	$3.2*10^{-4}$	$6.0*10^{-5}$
Bones	$8.4*10^{-1}$	$3.4*10^{-1}$	–

Accepted transfer factors

The analysis of experimental and literature data showed that the transfer of ^{137}Cs transfer into milk and meat of black and small cattle (sheep and goats) have practically had the same values. The difference was observed for ^{137}Cs transfer into chicken meat (2 orders of magnitude) and eggs (3 orders of magnitude). The factors of ^{90}Sr transfer into black and small

cattle (sheep and goats) and goat meat were practically of the same value. TF into meat of black cattle, meat of chickens and eggs are different in two orders, and into lamb – 3 orders. TF of $^{239+240}$Pu and ^{241}Am for certain animal products are in the IAEA doc. [37].

Based of the analysis, it was decided to use for prognosis the maximal concentrations of radionuclides for different types of livestock products presented in literature. In order to calculate possible concentrations of ^{137}Cs and ^{90}Sr in mutton, the maximal transfer factors obtained in the STS experiment were taken. As a result, the following transfer factors were adopted (table 49).

Table 49.

Accepted for prognosis factors of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am transfer into livestock products

Product type	TF			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Horse				
milk (koumiss)	$5.1*10^{-2}$	$8.0*10^{-3}$	$6.0*10^{-5}$	$5.0*10^{-4}$
meat (horseflesh)	$2.3*10^{-2}$	$2.8*10^{-3}$	$1.0*10^{-5}$	$1.0*10^{-5}$
Black cattle				
milk	$2.3*10^{-2}$	$2.8*10^{-3}$	$1.0*10^{-5}$	$1.0*10^{-5}$
meat (beef)	$5.1*10^{-2}$	$8.0*10^{-3}$	$6.0*10^{-5}$	$5.0*10^{-4}$
Sheep				
milk	$7.7*10^{-2}$	$5.6*10^{-2}$	$1.0*10^{-4}$	-
meat (mutton)	$2.3*10^{-1}$	$1.1*10^{-4}$	$5.3*10^{-5}$	$1.1*10^{-4}$
Goat				
milk	$1.3*10^{-1}$	$2.8*10^{-2}$	-	$6.9*10^{-6}$
meat	$4.8*10^{-1}$	$3.0*10^{-3}$	-	-
Poultry				
meat	12.0	$8.0*10^{-2}$	-	-
eggs	$4.5*10^{-1}$	$8.8*10^{-1}$	-	-

Assessment of radionuclide concentration in livestock products

In forecasting radionuclide concentrations in animal products the concentration in the diet and transfer factors (TF) from the diet to product are accounted for. Prediction of radionuclide content in animal products (C_{prod}) is calculated using the formula:

$$C_{прод} = C_{рац} \quad Kn\,,$$

where:

C_{diet} – daily diet radionuclides activity, Bq;

TF – transfer factor of radionuclides from diet into 1 k (kg) of product.

Daily average intake with food was formed by the following factors: intake of radionuclides with vegetable food, intake with soil particles on vegetation and intake with soil ingested from ground.

For calculation of radionuclide intake with soil particles on vegetable diet (dust) an experimental quantification of soil particles on the plants was conducted. To do this, the

dominant steppe plants were washed (19 washes). The average amount of soil particles per kilogram of dry mass of plants for different vegetation types is different: for fescue – 10.1 g, wormwood – 11.6 g, wheatgrass – 6.2 g, feather – 5.1 g. As a result, for calculation of intake with the dust of plants the mean value for steppe grasses – 8.1 g/kg was accepted, calculated based on all available values.

The daily intake of radionuclides with soil, when ingested by animals during grazing was calculated on the assumption that the black cattle during grazing period can consume up to 600 kg of soil, small cattle – up to 75 kg of soil [54, 55]. Thus, the daily intake of soil for horses and black cattle was 1.78 kg, for small cattle – 0.22 kg.

Based on these data and data on the maximal estimated specific activity of radionuclides in the steppe grasses (Table 29), and based on the average concentrations of radionuclides in the soil of the 1st zone having the highest values relative to the 2nd and 3rd zones, using information on daily intake of pasture forage [56], we calculated the daily intake of the radionuclides for animals grazed. The data are presented Table 50.

Table 50.

Results of calculation of possible radionuclide intake by farm livestock grazing in the study area

Farm animals	Aferage weight of animal unit, kg	Daily consumption rate of pasture forage (per dry mass), kg	Radionuclide intake into 1 animal, Bq							
			daily intake with forage (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake	daily intake with forage (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake
			^{137}Cs				^{90}Sr			
Horse	350-400	18	113.4	6.43	78.4	198.2	48.6	2.77	33.75	85.12
Cow	400	16	100.8	5.72	78.4	184.9	43.2	2.46	33.75	79.41
Sheep	50-60	2.5	15.75	0.89	9.80	26.4	6.75	0.38	4.22	11.35
Goat	50-60	2	12.6	0.71	9.80	23.1	5.4	0.31	4.22	9.93
Poultry	4-6	0.1*	0.13	-	-	0.13	0.11	-	-	0.11
			$^{239+240}$Pu				^{241}Am			
Horse	350-400	18	2.88	2.18	26.6	31.7	0.03	0.12	1.43	1.57
Cow	400	16	2.56	1.94	26.6	31.1	0.03	0.10	1.43	1.56
Sheep	50-60	2.5	0.4	0.30	3.36	4.03	0.004	0.016	0.18	0.20
Goat	50-60	2	0.32	0.24	3.33	3.89	0.0032	0.013	0.18	0.19
Poultry	4-6	0.1*	$1.6*10^{-5}$	-	-	$1.6*10^{-5}$	$5.0*10^{-4}$	-	-	$5.0*10^{-4}$

Table 51 shows the results of the predicted concentrations of radionuclides in animal products, in case they are produced in the study area and permissible concentrations of radionuclides in food stuffs, according to HS SRRS [43]. The permissible levels for $^{239+240}$Pu and ^{241}Am in animal products were calculated in the same manner as for meat of wild animals.

Table 51.

Calculated possible radionuclide intake by livestock grazing in the study area (based on the calculation of average radionuclide concentrations in the soil)

Product type	Predicted concentration, Bq/kg (permissible concentration, Bq / kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Horse				
Milk (koumiss)	4.56(100)	$3.38*10^{-1}$ (25)	$3.17*10^{-4}$ (2.5)	$6.61*10^{-7}$ (2.5)
Meat (horseflesh)	10.1 (200)	$6.81*10^{-1}$ (50)	$1.90*10^{-3}$ (5.0)	$7.87*10^{-4}$ (5.0)
Black cattle				
Milk	4.25 (100)	$2.22*10^{-1}$ (25)	$3.11*10^{-4}$ (2.5)	$6.55*10^{-7}$ (2.5)
Meat (beef)	9.43 (200)	$6.35*10^{-1}$ (50)	$1.87*10^{-3}$ (5.0)	$7.79*10^{-4}$ (5.0)
Sheep				
Milk	2.04 (100)	$6.36*10^{-1}$ (25)	$4.03*10^{-4}$ (2.5)	-
Meat (mutton)	6.08(200)	$1.25*10^{-3}$ (50)	$2.14*10^{-4}$ (5.0)	$2.19*10^{-5}$ (5.0)
Goat				
Milk	3.00 (100)	$2.78*10^{-1}$ (25)	-*	$1.34*10^{-6}$ (2.5)
Meat	11.1 (200)	$2.98*10^{-2}$(50)	-	-
Poultry				
Meat	1.55 (180)	$8.46*10^{-3}$ (80)	-	-
Eggs	$5.82*10^{-2}$ (80)	$9.31*10^{-2}$ (50)	-	-

The obtained values of the possible content of radionuclides in meat of farm animals in case they are grazed in designated zones, do not exceed the allowable values.

Thus, our studies have shown that in agricultural products both of plant and animal origin, produced in the "South East" territory of the STS the radionuclide concentration does not exceed the established norms, despite the fact that the calculations used the most conservative parameters used. Accordingly, the use of these products in food will not pose a threat on public health.

2.8.3. Experimental estimation of pollution levels of koumiss made in sarzhal village

In the territory adjacent to the southeastern part of the STS there is Sarzhal locality with a population of more than 2,000 people. The main activity in Sarzhal village is livestock farming. In particular, there is a shop in Sarzhal for production of the traditional Kazakh beverage – koumiss which is one of the main agricultural products in the area studied. The scope of koumiss production in 2010 exceeded 900 litres per day in summer and early autumn. Koumiss is sold then in settlements in surrounding areas and cities of Semey, Ust-Kamenogorsk, Almaty and Karaganda.

The koumiss is made by processing mare's milk, so the koumiss production shop purchases mare's milk from farmers in the region; most of the farms are located in the STS (Figure 1). The animals from these farms graze on the territory and around "Degelen" testing site where underground nuclear tests were conducted in the tunnels. Also in these areas fodder is harvested for animal feed in winter.

The earlier studies [29] found that the main long-lived artificial hazardous radionuclides accumulate in soils within "Degelen" testing site and do not overstep its boundaries. However, it was also revealed [90] that the radiation situation has been and will be greatly affected in the future by ^{3}H radionuclide which proliferates far beyond "Degelen" testing site with groundwater. In this regard, studies were carried out on the possible content of ^{3}H in koumiss produced in the shop in Sarzhal village and in farms located in southeastern part of the STS.

EXPERIMENT

^{3}H can inflow into mare's milk both during grazing of animals in the area adjacent to "Degelen" testing site and at stall feeding with hay harvested in the area. Therefore, ^{3}H content in the mare's milk was assessed during the period of pasture feeding in the area, and during stall feeding with hay harvested in the studied area. Koumiss was also sampled from the shop in Sarzhal village from a 60 l wood vessel in which the koumiss is brought to readiness. In total, 12 samples of koumiss were taken.

Preparation and analysis of samples

A sample for determination of ^{3}H was obtained by distillation of koumiss at 100˚C. The first obtained condensate in amounts of 10 ml was removed, and the following 5-6 ml of free water from koumiss was taken for analyses. Tritium activity was measured in this free water by beta-spectrometer TRI CARB 2900 TR with liquid scintillation method in compliance with ISO 9698 [61]. The analytical measurement error was less than 30%. So, the results below do not consider organically-bound tritium.

RESULTS OF INVESTIGATION

No ^{3}H was detected (table 52) in the koumiss samples taken from the koumiss production shop in Sarzhal village (from total volume of 60l after mixing of mare's milk in total capacity).

Table 52.

Determination of ^{3}H in the mare's milk (koumiss) produced in the the koumiss production shop in Sarzhal village

Sampling point	Sampling date	Specific activity of ^{3}H, Bq/L	Sampling point	Sampling date	Specific activity of ^{3}H, Bq/L
During pasture feeding			*During stall feeding*		
Shop for production of koumiss, Sarzhal village	04.09.2010	<19	Sarzhal village, small-scale family farms	21.03.2011	<12
	07.09.2010	<20		21.03.2011	<15
	07.09.2010	<20		21.03.2011	<12
	02.09.2010	<19		21.03.2011	<12
	20.09.2010	<12		21.03.2011	<13
	19.10.2010	<12		21.03.2011	<13

In koumiss, produced at stall feeding of animals with hay harvested from areas adjacent to "Degelen" sitw, in all cases, the specific activity of radionuclide ^{3}H was lower the limits of measurement (Table 52).

Overall, the studies have shown that the ^{3}H content does not exceed the lower limits of measuring equipment. Thus, koumiss, produced in farms located in the southeastern part of the STS, and in the koumiss production shop in Sarzhal is safe in terms of radiation factors.

3. ASSESSMENT OF DOSE LOADS ON POPULATION AND PERSONNEL LIVING AND WORKING ON THE STUDIED AREA

In this work when assessing the expected annual effective dose to the population the dose from natural radiation is not taken into account, including:

- external exposure from cosmic radiation;
- external and internal radiation from daughter products of radon and thoron;
- external and internal exposure from natural radionuclides in the surface soil.

To simplify the assessment of radiation dose, the following assumptions were accepted:

- Reduction in external doses rate was not considered in case soil is coverd with snow (in winter) and use of personal protective equipment;
- disregarded the changes in the dust level in the air depending on the season;
- disregarded the increase of height (1.5-2 meters) above the ground and shielding by vehicles (for farmers) or the body of a horse (for shepherd) at living and doing business in the "south-east" part of the STS;
- disregarded the internal dose from radionuclides in the water consumed from local water sources, as specific activity levels of artificial radionuclides in water are below the detection limits of the equipment used: ^{137}Cs and ^{90}Sr are <0.02 Bq/kg, $^{239+240}Pu$ <0.001. ^{3}H <15 Bq/kg [p. 4.4.2], which is 1-3 orders of magnitude below intervention levels for drinking water, according to HS SRRS ;
- disregarded the internal dose from the imported food.

It is assumed that the radioactive contamination is distributed evenly over the site, and the distribution in the soil horizons is exponential.

According to HS SRRS, dose factors used to estimate doses for intakes of radionuclides with air, are not divided into age groups. ^{238}Pu dose factors commensurate with $^{239+240}Pu$, isotopes $^{238+239+240}Pu$ were considered when assessing the dose.

3.1. The method for determining dose loads

To estimate dose loads to the population living in the "south-east" of the STS, from artificial radionuclides, the exposure pathways that the major contributor to the expected annual effective were considered:

- external exposure from artificial radionuclides in the surface (5 cm) layer of soil;
- internal exposure from inhalation of radionuclides;
- internal exposure consumption of food produced in the contaminated area.

The methodology for dose loads calculations is described in the monograph "Radioecological conditions of the northern territories of Semipalatinsk Test Site [38].

3.2. Initial data

3.2.1. Choice of Parameters used in calculating the dose loads

The results of the study determined that in the "south-east" of the STS the surface layer of soil contains the following main dose forming artificial radionuclides: ^{90}Sr, ^{137}Cs, $^{238+239+240}$Pu, ^{241}Am. The results of experimentally determined average content of artificial radionuclides in the surface (5 cm) layer of soil for 3 zones of the STS studied area are shown in Table 53.

Table 53.

Specific and areal activities of artificial radionuclides in the surface soil of the STS "south-east" part

^{137}Cs	^{90}Sr	$^{238+239+240}$Pu	^{241}Am
Zone 1			
Average specific activity, Bq/kg			
43.9	18.9	15	0.8
Areal activity of radionuclides at average specific activities, Bq/m²			
2853.5	1228.5	975	52
Zone 2			
Average specific activity, Bq/kg			
30.2	4.2	8.1	0.8
Areal activity of radionuclides at average specific activities, Bq/m²			
1963	273	526.5	52
Zone 3			
Average specific activity, Bq/kg			
19.0	3.4	3.7	0.7
Areal activity of radionuclides at average specific activities, Bq/m²			
1235	221	240.5	45.5

Parameter values used in assessments of dose loads from artificial radionuclides considered exposure pathways are given Table 54.

Table 54.

Coefficients used to estimate the dose loads

Coefficients	Coefficient values			
	^{137}Cs	^{90}Sr	$^{238+239+240}$Pu	^{241}Am
B_{sg}, mGy m²/h·kBq	$2.5\cdot10^{-6}$	$1.0\cdot10^{-9}$	$1.3\cdot10^{-9}$	$9.7\cdot10^{-8}$
$e_{inhpop.}$ Sv/kg	$4.6\cdot10^{-9}$	$5.0\cdot10^{-8}$	$5.0\cdot10^{-5}$	$4.20\cdot10^{-5}$
e_{dt} (adult), Sv/kg	$1.3\cdot10^{-8}$	$2.8\cdot10^{-8}$	$2.5\cdot10^{-7}$	$2.0\cdot10^{-7}$
e_{dt} (7-12 year old children), Sv/kg	$1.0\cdot10^{-8}$	$6.0\cdot10^{-8}$	$2.7\cdot10^{-7}$	$2.2\cdot10^{-7}$
e_{dt} (1-2 year old infant), Sv/kg	$1.2\cdot10^{-8}$	$7.3\cdot10^{-8}$	$4.2\cdot10^{-7}$	$3.7\cdot10^{-7}$

3.2.2. Parameters of annual consumption of food and expected specific activities of radionuclides in products

To assess the internal dose from food produced in the contaminated area, one needs to know the annual food consumption rate.

Rates of staple foodstuffs consumption for different social groups that represent the minimal food needed to ensure human life, are in the Law of the Republic of Kazakhstan dated November 16, 1999 № 474-I "On Poverty Level" [57].

These standards are averaged values for the people of Kazakhstan and can differ significantly for different groups and strata of the population.

Therefore, to estimate dose loads from the consumption of food produced within the study area, a questionnaire survey of the population was carried out refine the food basket. The public were invited to answer the following questions: basic characteristics of the household; if there is a garden; types of economic activities within the STS territory; annual consumption of manufactured food products. The survey found that the volume and structure of population's diet living in the ST, is different from the minimum standards of staple food consumption, towards increasing the consumption of meat and dairy products. Based on the survey and living conditions of the population, changes were made to the norms of staple food consumption that can be produced and consumed by the population in the study area (Table 55).

Table 55.

Amount of consumed food grown and produced in the "south-east" part of the STS

Food stuff	Standards of food consumption, kg/year			
	7-12 year old children	1-2 year old infant*	man	woamn
First quality enriched wheat flour	6.5	4	16.6	13.2
Bread made from enriched wheat flour 1 quality	39.6	20	88.6	70.2
Rye-bread	2.5	2	5.8	4.6
Pasta	3.5	2	5.2	4.1
Ground oat	1.8	1.8	2.4	1.9
Pea, bean	1	-	2.6	2
Potato	66.5	5	117.9	94.1
White cabbage	13.6	0.5	31.6	25
Carrot	19.2	5	23	18.2
Tomato	3.1	0.5	6.2	4.9
Cucumber	3.1	0.3	6.2	4.9
Beet	3.1	0.5	6.2	4.9
Beef	12.3	2	30*	25*
Horseflesh	1.6	-	40*	32*
Mutton	5.7	-	40*	32*
Chicken meat	4.6	0.5	10*	8*
Milk, litre	150*	180	200*	150*
20% fat sour cream	2.8	0.5	30я*	18*
Koumiss, litre	-	-	60*	50*
Low-fat cottage cheese	4.4	4.4	30*	20*
Eggs, pcs	205	40	200*	180*
Note: * – changes have been made according to the survey				

The forecasted specific activities of radionuclides in animal and plant products were calculated using the transfer factors of radionuclides presented in the IAEA documents [37]. Based on the selected transfer factors in crop and livestock products the expected specific activity of radionuclides have been calculated, which are then used to assess the dose loads from intake of artificial radionuclides through food chains.

The expected specific activities of radionuclides in crop and livestock products at their production in the study area are given in Table 56–57.

Table 56.

The expected specific activity of radionuclides in animal products at average contents of artificial radionuclides in surface soil of the study area

Product type	Specific activity of radionuclides, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Black cattle				
Milk	4.3	$2.2\cdot10^{-1}$	$3.1\cdot10^{-4}$	$6.6\cdot10^{-7}$
Meat (beef)	9.4	$6.4\cdot10^{-1}$	$1.9\cdot10^{-3}$	$7.8\cdot10^{-4}$
20% fat sour cream	$8.5\cdot10^{-1}$	$4.5\cdot10^{-2}$	$6.2\cdot10^{-5}$	$1.3\cdot10^{-7}$
Low-fat cottage cheese	$1.7\cdot10^{-1}$	$8.9\cdot10^{-3}$	$1.2\cdot10^{-5}$	$2.6\cdot10^{-8}$
Horseflesh				
Meat	10.1	$6.8\cdot10^{-1}$	$1.9\cdot10^{-3}$	$7.9\cdot10^{-4}$
Koumiss (milk)	4.6	$2.4\cdot10^{-1}$	$3.2\cdot10^{-4}$	$6.6\cdot10^{-7}$
Sheep				
Meat (mutton)	6.1	$1.2\cdot10^{-3}$	$2.2\cdot10^{-4}$	$2.2\cdot10^{-5}$
Poultry				
Meat	1.5	$8.4\cdot10^{-3}$	-	-
Eggs	$5.8\cdot10^{-2}$	$9.3\cdot10^{-2}$	-	-
Note: "-" – No estimated values due to TF absence				

Table 57.

Expected content of radionuclides in crop products at their production in the study area at average specific activity in the surface soil layer for the zones 1, 2 and 3

Product type	Specific activity of radionuclides, Bq/kg					
	^{137}Cs			^{90}Sr		
	I	II	III	I	II	III
Grain crop						
Rye	1.3	$8.8\cdot10^{-1}$	$5.5\cdot10^{-1}$	1.05	$2.3\cdot10^{-1}$	$1.3\cdot10^{-1}$
Wheat	1.3	$8.9\cdot10^{-1}$	$5.6\cdot10^{-1}$	1.06	$2.4\cdot10^{-1}$	$1.3\cdot10^{-1}$
Oat	2.4	1.7	1.1	1.05	$2.3\cdot10^{-1}$	$1.3\cdot10^{-1}$
Leaf vegetable						
Cabbage	$2.9\cdot10^{-1}$	$1.9\cdot10^{-1}$	$1.2\cdot10^{-1}$	1.8	$4.0\cdot10^{-1}$	$2.2\cdot10^{-1}$
Legumes						
Bean. pea	$4.9\cdot10^{-1}$	$3.3\cdot10^{-1}$	$2.1\cdot10^{-1}$	9.6	2.1	1.2
Fruited vegetables						
Tomato	$7.5\cdot10^{-2}$	$5.2\cdot10^{-2}$	$3.2\cdot10^{-2}$	$6.8\cdot10^{-1}$	$1.5\cdot10^{-1}$	$8.1\cdot10^{-2}$
Cucumber	$6.2\cdot10^{-2}$	$4.3\cdot10^{-2}$	$2.7\cdot10^{-2}$	$5.6\cdot10^{-1}$	$1.3\cdot10^{-1}$	$6.8\cdot10^{-2}$
Tuberous root						
Potato	$3.6\cdot10^{-1}$	$2.5\cdot10^{-1}$	$1.6\cdot10^{-1}$	$3.1\cdot10^{-1}$	$7.0\cdot10^{-2}$	$3.8\cdot10^{-2}$
Beet (roots)	$2.8\cdot10^{-1}$	$1.9\cdot10^{-1}$	$1.2\cdot10^{-1}$	1.6	$3.5\cdot10^{-1}$	$1.9\cdot10^{-1}$
Carrot (roots)	$2.4\cdot10^{-1}$	$1.7\cdot10^{-1}$	$1.1\cdot10^{-1}$	1.4	$3.0\cdot10^{-1}$	$1.6\cdot10^{-1}$

Product type	Specific activity of radionuclides, Bq/kg					
	$^{239+240}$Pu			^{241}Am		
	I	II	III	I	II	III
Grain crop						
Rye	$1.6\cdot10^{-4}$	$6.4\cdot10^{-5}$	$3.9\cdot10^{-5}$	$4.9\cdot10^{-3}$	$4.9\cdot10^{-3}$	$4.3\cdot10^{-3}$
Wheat	$1.6\cdot10^{-4}$	$6.4\cdot10^{-5}$	$3.9\cdot10^{-5}$	$5.0\cdot10^{-3}$	$5.0\cdot10^{-3}$	$4.4\cdot10^{-3}$
Oat	$1.3\cdot10^{-4}$	$6.4\cdot10^{-5}$	$3.9\cdot10^{-5}$	$4.9\cdot10^{-3}$	$4.9\cdot10^{-3}$	$4.3\cdot10^{-3}$
Leaf vegetable						
Cabbage	$1.3\cdot10^{-4}$	$5.2\cdot10^{-5}$	$3.2\cdot10^{-5}$	$9.6\cdot10^{-6}$	$9.6\cdot10^{-6}$	$8.4\cdot10^{-6}$
Legumes						
Bean. pea	$2.2\cdot10^{-4}$	$8.9\cdot10^{-5}$	$5.5\cdot10^{-5}$	$1.4\cdot10^{-4}$	$1.4\cdot10^{-4}$	$1.2\cdot10^{-4}$
Fruited vegetables						
Tomato	$2.0\cdot10^{-5}$	$7.9\cdot10^{-6}$	$4.9\cdot10^{-6}$	$1.6\cdot10^{-5}$	$1.6\cdot10^{-5}$	$1.4\cdot10^{-5}$
Cucumber	$1.7\cdot10^{-5}$	$6.6\cdot10^{-6}$	$4.1\cdot10^{-6}$	$1.3\cdot10^{-5}$	$1.3\cdot10^{-5}$	$1.2\cdot10^{-5}$
Tuberous root						
Potato	$8.2\cdot10^{-4}$	$3.2\cdot10^{-4}$	$2.0\cdot10^{-4}$	$6.4\cdot10^{-5}$	$6.4\cdot10^{-5}$	$5.6\cdot10^{-5}$
Beet (roots)	$1.1\cdot10^{-3}$	$4.2\cdot10^{-4}$	$2.6\cdot10^{-4}$	$4.6\cdot10^{-5}$	$4.6\cdot10^{-5}$	$4.03\cdot10^{-5}$
Carrot (roots)	$9.4\cdot10^{-4}$	$3.7\cdot10^{-4}$	$2.3\cdot10^{-4}$	$4.03\cdot10^{-5}$	$4.03\cdot10^{-5}$	$3.5\cdot10^{-5}$

3.3. Description of possible scenarios for behaviour of population in "The Southeast" of STS

In assessing the doses loads to the population living in wintering sites of "south-eastern" parts of the STS, an agricultural scenario of behaviour was considered:

Agricultural scenario

This scenario considers life activities of the population on the studied lands.

Farmer's family (shepherd's) consists of 4 people (adults – farmer (shepherd) and a housewife; children – one 1-2 year old child, another 7-12 year old child). They consume products of plant and animal origin in the study area. Choice of this age group of children was conditioned that the basic food for 1-2 year child is dairy products; 7-12 year old child is examined by parameters of the volume of air inhaled and standards of food consumption as a middle element.

Dustiness of air in the room for all ages was accepted to be 10^{-7} kg/m^3. Shielding factor (house walss) was taken to be 0.4 [58].

The agricultural scenario includes the following activities.

1. Farmer cultivates crops and hay on the land (farm), located near his residence site. It is assumed that the farmer spends part of his time in the cultivation area and to take care of plants, rest of the time he spends in the garden, on the courtyard, taking care of the cattle, and at home. The dose for the farmer is calculated on the assumption that he spends 8 hours a day in open air. Air dustiness while working on the farm and courtyard is taken as 10^{-6} kg/m^3. The farmer is only an adult worker (male, female). When working on a farm the respiration intensity is taken to be 5.6 m^3/h – for adults.
2. Shepherd pastures in a radius of 10-15 km from his residence and cares for animals in stall barn housing. Working day of the shepherd on average is 10

hours in the open air, the rest of the time he spends at home. Air dustiness in grazing animals and in the care of the cattle is taken to be 10^{-6} kg/m^3, 10^{-7}kg/m^3 at home. The shepherd is only an adult worker (male).

3. Housewife (female) is engaged in housekeeping, working in the garden and on the courtyard, looking after cattle. She spends outdoors 8 hours a day. Air dustiness is accepte to be 10^{-6}kg/m^3. Respiration rate – 2.8 m^3/h.
4. 7-12 year old children spend outdoor (playing) an average of 8 hours per day. Air dustiness is accepted to be 10^{-6} kg/m^3.
5. 1–2 old child spends outdoor on average 4 hour a day. Air dustiness is accepted to be 10^{-6} kg/m^3.

Summary on the time spent by the population in the open air and in the room is Table 58.

Table 58.

Time T spent on open air and inside the premises

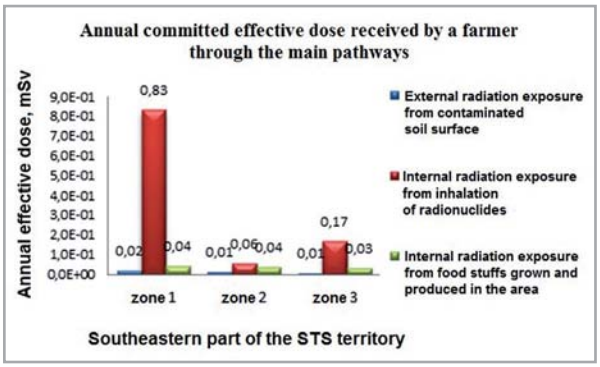
Factor	Measurement units	Lifestyle scenario
The time spent in the open air	hour/year	2920 (farmer, housewife) 3600 (shepherd) 2920 (7–2 year old children) 1460 (1–2 year old child)
Time spent indoors	hour/year	5840 (farmer, housewife) 5160 (shepherd) 5840 (7–2 year old children) 7300 (1–2 year old child)

3.4. Assessment of dose loads to the population living and engaged in activity in the study area

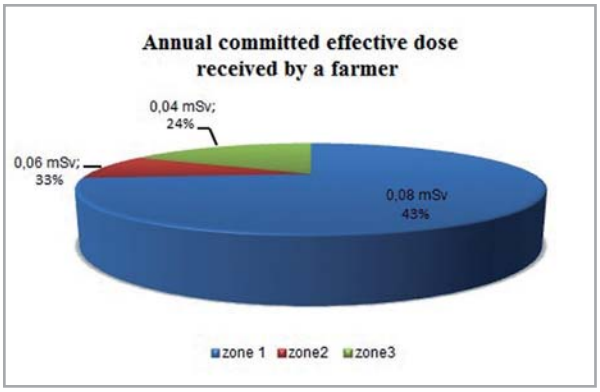
Assessing the dose loads on the population living in wintering sites of "south-eastern" parts of the STS, the following has been revealed.

The histogram (Figure 32) shows the distribution of farmer's annual committed effective dose received though different ways of radiation exposure for each specified zone.

The figure shows that the main contribution to the farmer's radiation exposure in zones I, II and III gives the internal radiation dose produced by foodstuffs grown and produced in the area, where the main contribution is made by ^{137}Cs.



a)

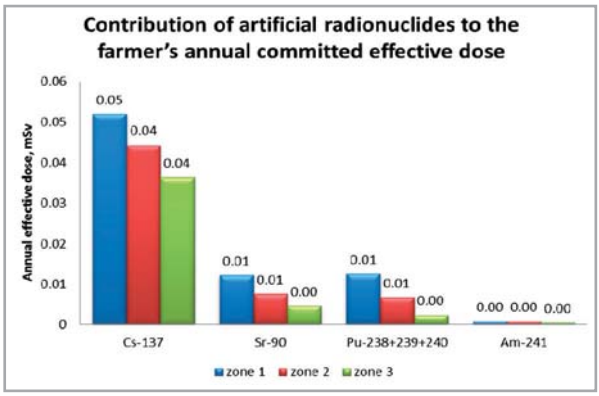


b)

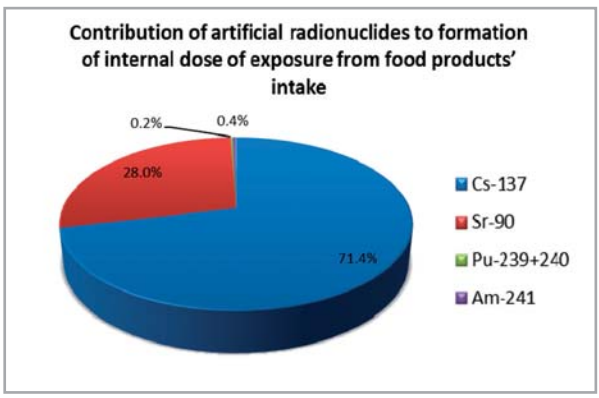
Figure 32. Annual committed effective dose received by a farmer according to the agricultural scenario of his behavior: a) through the main pathways of radiation exposure in zones I – III in southeastern part of the STS territory, b) total annual committed effective dose in zones I – III in southeastern part of the STS territory

Figure 33 shows the contribution of artificial radionuclides to the farmer's annual committed effective dose from different ways of radiation exposure for each specified zone.

The main contribution to the farmer's radiation exposure for average values of radionuclide specific activity in the surface soil layer in zones I, II and III is made by the internal exposure from the intake of foodstuffs grown and produced on the studied area (~56%, ~63%, ~77%). The external exposure dose from contaminated soil is 27% of the annual effective dose in zone I, 25% in zone II and 17% in zone III. The main contribution to the farmer's external dose from the radiation by raduonuclides is made by ^{137}Cs. The main contribution to the internal exposure from inhalation of raduonuclides is made by $^{238+239+240}$Pu (96% in the zone I).



a)

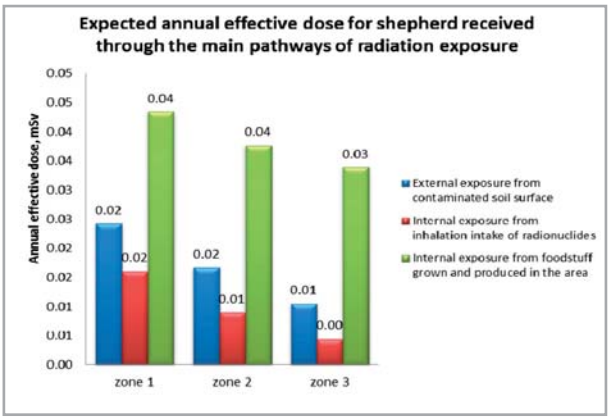


b)

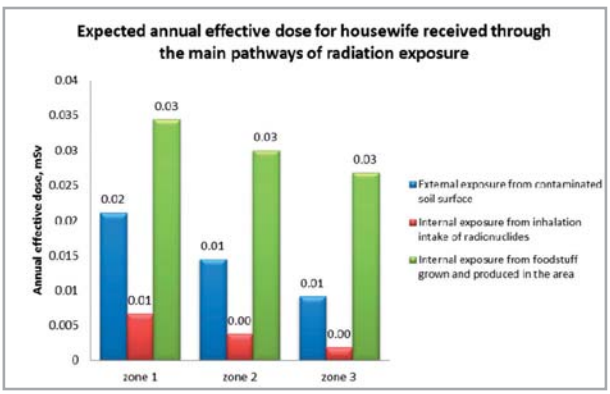
Figure 33. Contribution of artificial radionuclides to the farmer's annual committed effective dose: a) through the main pathways of radiation exposure in zones I – III in southeastern part of the STS territory; b) internal exposure from foodstuffs grown and produced in zone I

In zone I the contribution to the annual effective dose from intake of raduonuclides with foodstuffs for adults is equal to 28% for crop products and 72% for animal products. The main contribution to the annual committed effective dose from intake of raduonuclides with animal products for average values of radionuclide specific activity in the surface soil layer is provided by milk products – 55% for adults.

Figure 34 shows the values of annual committed effective doses received by a shepherd according to the agricultural scenario of his behavior for average values of specific activities of radionuclides in the surface soil layer in zones I-III.



a)



b)

Figure 34. Annual committed effective dose of a shepherd and a housewife received through the main pathways of radiation exposure in zones I – III in southeastern part of the STS territory according to the agricultural scenario of their behavior

According to the agricultural scenario of shepherd's behavior, annual committed effective doses received by him through the main pathways of intake of artificial radionuclides for average values of specific activities of radionuclides in the surface soil layer do not exceed maximum permissible values and are equal to ~$8.4 \cdot 10^{-2}$ μSv in zone I, ~$6.3 \cdot 10^{-2}$ μSv in zone II and ~$4.9 \cdot 10^{-2}$ μSv in zone III. The main contribution to the radiation exposure in zones I-III is made by internal exposure from intake of foodstuffs (~$4.3 \cdot 10^{-2}$, ~$3.8 \cdot 10^{-2}$ and ~$3.4 \cdot 10^{-2}$ μSv, respectively). In zone I the contribution to the annual effective dose from intake of raduonuclides with foodstuffs for adults is 28 % for crop products and 72 % for animal products. The main contribution to the annual committed effective dose from intake of raduonuclides with animal products for average values of radionuclide specific activity in the surface soil layer – 55 % – is made by milk products.

The annual committed effective doses received by a housewife through the main pathways of intake of artificial radionuclides according to the agricultural scenario of her behavior for average values of specific activities will be ~$6.2 \cdot 10^{-2}$ μSv in zone I, ~$4.8 \cdot 10^{-2}$ μSv in zone II and ~$3.8 \cdot 10^{-2}$ μSv in zone III. The main contribution to the radiation exposure is made by the internal exposure from the intake of foodstuffs grown and produced on the studied area where the main contribution is made by radionuclide ^{137}Cs.

Figure 35 shows the values of annual committed effective doses received by local people through the main pathways according to the agricultural scenario for average values of specific activities of artificial radionuclides in the surface soil layer in zone I.

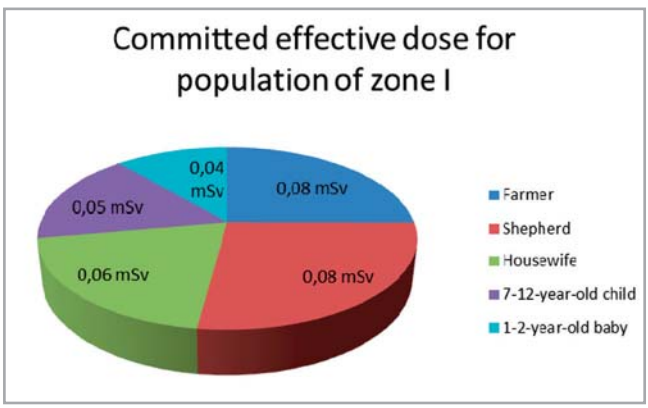


Figure 35. A graph of committed effective dose for population of zone I

An assessment of the radiation exposure of people living and working on the studied area showed that their committed effective dose would not exceed the main limit of doses permissible for population (1 μSv/h).

CONCLUSION

The studies revealed that presence and amounts of artificial radionuclides in environment of southeastern part of STS have beed stipulated both by global radioactive fallouts and local fallout after the first fusion test and after one of the model experiments.

Radionuclide analysis of the environmental samples has shown that the average content of natural radionuclides in the soil of study area is typical for soils of Kazakhstan, no geochemical anomalies have been identified. None of the samples studied by gamma spectral analysis had any other artificial radionuclides other than ^{137}Cs and ^{241}Am, and in case ^{60}Co, ^{152}Eu are found, they will be below the detection limit of the measuring equipment, which means they pose no harmful to humans and environment. Radiochemical analysis of environmental samples determined in them such long-lived radionuclides as ^{90}Sr and $^{239+240}$Pu.

The territory can be divided into three zones by distribution of artificial radionuclides ^{137}Cs, ^{90}Sr and $^{239+240}$Pu. Average specific activity of ^{137}Cs and ^{90}Sr in the soils of the area is at background of global fallout, or slightly (1.5 times) exceeds it. Average specific activity

of $^{239+240}$Pu is 1.5-6 times higher than background of global fallout. The maximum specific activity of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu is below the levels that characterize the ecological situation as "relatively satisfactory situation" in soil classifying regulatory documents (parameter of soil contamination with long-living decay products due to nuclear explosions in the Governmental Decree No.653 from July 31, 2007 "Criteria for Environmental Assessments of Lands"). In accordance with these criteria, the study area, by contents of $^{239+240}$Pu in the soil, is categorized as an area with "relatively satisfactory environmental situation".

Radionuclide contents in vegetation cover there do not exceed the levels established in the "Provisional Acceptable Levels for Radionuclide Contents in Objects under Regulatory Control of the Ministry of Agriculture". In general, radionuclide contents in vegetation do not impose radiological risks for population making the vegetation suitable for certain types of commercial use including agricultural pasturing both in the present time and in the future.

Specific activity of artificial radionuclides in the body of wild animals inhabiting the "south-east" of the STS will be at an acceptable level even with their migration from nearby testing ground of the STS. Predictive values of radionuclide content in meat of wild commercial animals, obtained from the research, are far below the permissible levels. Consumption of meat from animals that are hunted, is not dangerous to people in terms of radiation.

In the prepared materials the authors made a prognostic evaluation of radiation characteristics of products which can be produced on the territory studied. The estimated specific activity of artificial radionuclides in crop and livestock products is significantly below the permissible content, even if produced in the area with high specific activity of transuranic elements. Thus, the expected content of radionuclides in food produced in the area will not exceed the permissible levels according Hygienic Standards "Sanitary requirements for radiation safety".

The results of these studies suggest that the levels of radionuclides in groundwater and surface waters in the southeastern part of the STS allow using this land for any kind of economic activity without any restrictions. The radionuclide content in the waters of the surveyed area does not exceed the intervention level at intake with food and water for the population, according to HS SRRS [28]. Content of radionuclides in the atmospheric air within the study area is safe for the person staying right in this area.

The final conclusion on suitability of the studied lands for living and commercial activities is based on assessment of dose loads on population to inhabit these lands. Maximal acceptable effective dose for population comprises 1 mSv/year. Our worst-case scenario for a subsistence farmer living within the contaminated area predicts annual effective dose per person will be 0.8 mSv that exceeds 0.3 mSv and is below the intervention level established in Hygienic standards "Sanitary requirements for radiation safety" (Annex 7).

So, according to the assessment of integral radiological parameters and based on current regulatory requirements, **the entire studied territory can be utilized without any restriction.**

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ССП АУМАҒЫНДАҒЫ «ОҢТҮСТІК-ШЫҒЫС» БӨЛІГІНІҢ (САРЖАЛ А. АУМАҒЫ) РАДИОЭКОЛОГИЯЛЫҚ АХУАЛЫ

[1]Стрильчук Ю.Г., [1]Лукашенко С.Н., [1]Каширский В.В., [1]Яковенко Ю.Ю., [1]Айдарханов А.О., [1]Ляхова О.Н., [1]Ларионова Н.В., [1]Магашева Р.Ю., [1]Паницкий А.В., [1]Субботин С.Б., [1]Құндызбаева А.А., [1]Топорова А.В., [1]Тоневицкая О.В., [2]Бахтин Л.В.

[1] ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан
[2]ҚР ҰЯО Геофизикалық зерттеулер институты, Курчатов, Қазақстан

Мақалада, Семей сынақ полигоны (ССП) аумағының оңтүстік-шығыс бөлігінде орналасқан, ауқымы 850 км^2 болатын Саржал а. аумағына жүргізілген радиоэкологиялық зерттеулердің нәтижелері келтірілген. Зерттеу жүргізілген аумақтың шегінде табиғи орта нысандарының қазіргі радиоэкологиялық жағдайына: құмдақтопырақ, су нысандары, ауа бассейні, өсімдік жамылғысы, жануарлар әлеміне бағалау жұмыстары жүргізілді. Топырақтағы техногенді ^{137}Cs, ^{90}Sr және $^{239+240}$Pu радионуклидтердің құрамының деңгейі бойынша аумақты үш аймаққа бөлуге болады. Екі аймақтың топырағындағы радионуклидтердің жоғары құрамы, ССП аумағында өткізілген сынақтарға байланысты шартталған. Барлық зерттелген аумақтағы ^{137}Cs және ^{90}Sr радионуклидтерінің тиесілі белсенділігінің орташа мәні ғаламдық түсулердің аясының деңгейінде, немесе болмашы түрде ғана жоғары (1,5 есеге дейін). $^{239+240}$Pu радионуклидінің тиесілі белсенділігінің орташа мәні ғаламдық түсулердің аясынан 1,5-6 есеге жоғары.

Қоршаған орта нысандарындағы және азық-түлік өнімдеріндегі радионуклидтердің құрамы жайлы деректердің негізінде тұрғындарға түсетін дозалық жүктемеге бағалау жасалды. «Ластанған аумақтың шегінде табиғи шаруашылық жүргізуші фермер» сценарийі «нашар» болған жағдайда, бір адамға түсетін жылдық күтілетін тиімді доза 0,08 мЗв құрайды, ол 0,3 мЗв аспайды және «Радиациялық қауіпсіздікті қамтамасыз етуге қойылатын санитарлық-эпидемиологиялық талаптар» Гигиеналық нормативтерге сәйкес араласу деңгейінен төмен.Өткізілген кешенді зерттеулердің және тұрғындарға түсетін күтілген дозалық жүктемелердің негізінде, ҚР нормативті базасының қолданыстағы талаптарына сәйкес, барлық зерттелген аумақты ешбір шектеусіз пайдалануға болады.

Аталған зерттеулер, одан ары қарай жерлерді шаруашылық айналысына беру мақсатында жүргізілді.

Кілт сөздер: ядролық сынақтар, радиоэкология, радиоактивті ластану, радионуклидтер, өсімдік жамылғысы, супайдалану нысандары, жүріп-тұру сценарийі, дозалық жүктемелер.

РАДИОЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ «ЮГО-ВОСТОЧНОЙ» (РАЙОН С. САРЖАЛ) ЧАСТИ ТЕРРИТОРИИ СИП

[1]Стрильчук Ю.Г., [1]Лукашенко С.Н., [1]Каширский В.В., [1]Яковенко Ю.Ю., [1]Айдарханов А.О., [1]Ляхова О.Н., [1]Ларионова Н.В., [1]Магашева Р.Ю., [1]Паницкий А.В., [1]Субботин С.Б., [1]Кундузбаева А.А., [1]Топорова А.В., [1]Тоневицкая О.В., [2]Бахтин Л.В.

[1] Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан
[2]Институт геофизических исследований НЯЦ РК, Курчатов, Казахстан

В статье представлены результаты радиоэкологических исследованийюго-восточной части территории Семипалатинского испытательного полигона (СИП), расположенной в районе с. Саржал, на площади 850 км^2. В пределах обследованной территории проведена оценка современного радиоэкологического состоянияобъектовприродной среды: почвогрунтов, водных объектов, воздушного бассейна, растительного покрова, животного мира. По уровням содержания в почве техногенных радионуклидов ^{137}Cs, ^{90}Sr и $^{239+240}$Pu территорию можно разделить на три зоны. Повышенное содержание радионуклидов в почвах в двух зонах обусловлено испытаниями, проведенными на территории СИП. Средние значения удельной активности радионуклидов ^{137}Cs и ^{90}Sr в почвах на всей обследованной территории находятся на уровне фона глобальных выпадений, либо незначительно (до 1,5 раз) превышают его. Средние значения удельной активности радионуклида $^{239+240}$Pu в 1,5-6 раз превышают фон глобальных выпадений.

На основании данных о содержании радионуклидов в объектах природной среды и продуктах питания была сделана оценка дозовых нагрузок на население. При условии «наихудшего» сценария «фермер, ведущий натуральное хозяйство в пределах загрязненной территории», ожидаемая годовая эффективная доза для человека составит 0,08 мЗв, что не превысит 0,3 мЗв и является ниже уровня вмешательства, согласно Гигиеническим нормативам «Санитарно-эпидемиологические требования к обеспечению радиационной безопасности». На основании проведенного комплексного обследования и ожидаемых дозовых нагрузок на население, в соответсвиис существующими требованиями нормативной базы РК, вся обследованная территория может использоваться без ограничений.

Данные исследования проведены с целью дальнейшей передачи земель в хозяйственный оборот.

Ключевые слова: ядерные испытания, радиоэкология, радиоактивное загрязнение, радионуклиды, растительный покров, объекты водопользования, сценарий поведения, дозовые нагрузки.

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CURRENT RADIOECOLOGICAL SITUATION AT "SARY-UZEN" SITE OF THE STS

[1] Subbotin S.B., [1] Strilchuk Yu.G., [1] Novikova E.A., [1] Romanenko V.V., [2]Pestov E.Yu., [2] Bakhtin L.V.

[1]Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan
[2]Institute of Geophysical Research NNC RK, Kurchatov, Kazakhstan

The paper describes the factors and mechanisms of radiological situation formation at "Sary-Uzen" site. Studies of radioactive contamination of soils within the near-mouth areas of emplacement wells are reported. Current radioecological situation of groundwater at the site, as well as possible pathways of contaminated groundwater migration beyond "Sary-Uzen" site is considered.

Keywords: "Sary-Uzen" site, well head, emplacement well, contamination of soil, groundwater migration.

INTRODUCTION

After the shutdown of the Semipalatinsk Test Site (STS), the problem of the underground nuclear explosions (UNE) has been studied in Kazakhstan since the early nineties of the last century. The bulk of the operations being done are concentrated on collection of data on the radionuclides distribution, primarily in the soil, surface water and groundwater and in the air. Investigations are being carried out to study underground space at UNE sites. At present because having no techniques for underground radioecological mapping and assessing the technological processes dynamics at depth, the NNC RK is developing recommendations on the techniques for comprehensive assessment of the mineral resources at the UNE sites.

The UNE sites must be categorized as potentially dangerous facilities similar to long-term underground disposal of radioactive waste (RW). In order to allocate exclusion zones within which the use of underground resources should be prohibited, including groundwater it is necessary to conduct a phased set of investigations. This issue has become particularly relevant in the present during the comprehensive researches in order to transfer the STS territories to civilian use. For reliable identification of trends and forecasting the geoecological conditions in the UNE areas one of the main objectives is to study in time the cause-and-effect relationships, the adverse effects with post-explosion deep structure of the investigated geological environment blocks and ongoing in them geodynamic, hydrodynamic and radiomigration processes.

This review article presents research findings of the NNC RK divisions in different years focused on the problems on one of the STS main testing grounds – "Sary-Uzen".

1. BACKGROUND ON THE "SARY-UZEN" SITE

1.1. Nuclear tests at "Sary-Uzen" Site

According to the file materials [1] in the period from 1965 to 1980 at "Sary-Uzen" site 24 underground tests were conducted in 25 emplacement wells. One of the underground nuclear tests – "Lazurit" was carried out in the immediate vicinity of "Sary-Uzen" site, in Murzhik mountain range. Arrangement of the wells is shown in the figure (Figure 1).

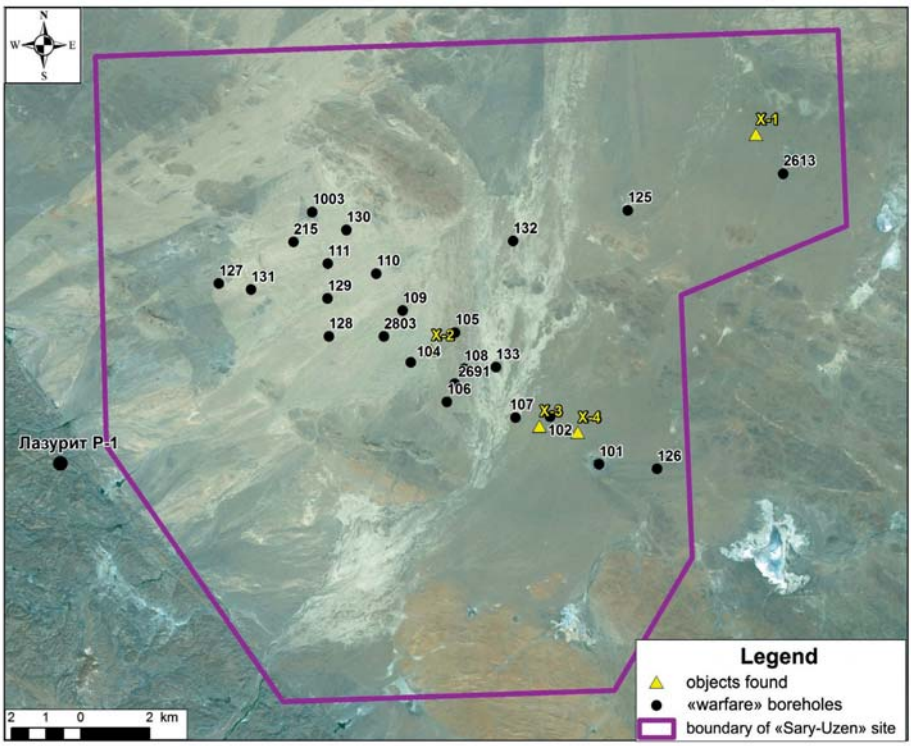


Figure 1. Satellite image of "Sary-Uzen" site. Arrangement of the emplacement well on the site

It is worth noting that there is no official information about the location of the emplacement wells, namely their coordinates. When locating the emplacement wells the IRSE NNC RK specialists used satellite image of the test site and arrangement of the wells at "Sary-Uzen" site that is presented in Figure 1. The satellite imagery interpretation and comparison of the data with the existing scheme helped to specify the positions of all wells and determine their approximate location.

The field survey at "Sary-Uzen" site found 24 emplacement wells, the coordinates of which are given in Table 1. More information about the tests at the site is available in references [2, 3, 4]. In addition, 4 more well heads were found, by external characteristics similar to the emplacement wells, which have been assigned the following numbers: No. X-1, X-2, X-3 and X-4 (Figure 1).

Table 1.

Information on the wells and "Sary-Uzen" site

No.	Well No.	Actual Elevation, m	North latitude	Eastern longitude	Explosion date	Time (GMT), hours, minutes, seconds	Explosion power, kt	Explosion magnitude	Depth of the charge, m	Test goal	Radiation effect*
1	101	-	49 55 24.4	77 44 43.6	18.12.1966	4 58 00.0	n20-150	5.8	427	TIC	PCE(ARS) Release of about 10% of radioactive yield from the explosion. Radiation levels on the heap exceeded 1,000 R/h. Increased radiological contamination; protective zone established.
2	102	458.1	49 56 05.5	77 43 25.5	16.09.1967	4 04 00.3	0.001-20	5.3	230	INW	PCE
3	104	-	49 57 10.6	77 40 20.7	21.07.1970	3 02 59.7	0.001-20	5.4	225	INW	FCE
4	105	-	49 57 36.5	77 41 25.7	22.09.1967	5 04 00.0	10	5.2	229	INW	FCE
5	106	457.3	49 56 32.6	77 41 10.6	22.11.1967	4 03 59.9	0.001-20	4.8	227	INW	FCE
6	107	461	49 56 16.0	77 42 49.0	28.12.1969	3 47 00.2	46	5.7	388	INW	FCE
7	108	454.5	49 57 03.0	77 41 37.0	31.05.1969	5 01 59.4	0.001-20	-	258	INW	PCE
8	109	450.1	49 57 56.5	77 40 13.0	16.02.1979	4 04 00.5	0.001-20	5.4	-	INW	PCE
9	110	450.3	49 58 33.4	77 39 34.7	06.06.1971	4 02 59.7	16	5.5	299	INW	PCE
10	111	456.4	49 58 42.3	77 38 27.0	09.10.1971	6 02 59.7	12	5.3	237	INW	PCE(ARS) Rapid and intensive proliferation of RNG through the emplacement well and cracks in the epicentral zone. Radiation levels reached 200 R/h. No residual contamination.

No.	Well No.	Actual Elevation, m	North latitude	Eastern longitude	Explosion date	Time (GMT), hours, minutes, seconds	Explosion power, kt	Explosion magnitude	Depth of the charge, m	Test goal	Radiation effect*
11	125	-	49 59 26.2	77 45 41.2	04.11.1970	6 02 59.8	0.001-20	5.4	249	TIC	PCE
12	126	426.7	49 59 49.4	77 49 32.0	04.04.1980	5 32 59.83	0.001-20	4.9	-	INW	FCE
13	127	476.9	49 58 27.5	77 35 48.1	21.10.1971	6 02 59.7	23	5.5	324	INW	PCE
14	128	462.1	49 57 35.3	77 38 24.8	02.09.1972	8 56 59.9	2	4.9	185	INW	PCE
15	129	457.8	49 58 10.2	77 38 24.7	19.06.1971	4 04 00.1	0.001-20	5.4	290	INW	PCE
16	130	452.1	49 59 12.7	77 38 55.9	29.03.1977	-	20-150	5.4	-	INW	PCE
17	131	470.9	49 58 20.9	77 36 34.5	19.04.1973	4 32 59.9	0.001-20	5.4	-	INW	PCE
18	132	443.1	49 58 56.7	77 42 27.2	26.08.1972	3 46 59.7	0.001-20	5.3	285	INW	PCE
19	133	454.8	49 57 01.4	77 42 25.2	04.08.1976	-	0.001-20	4.1	-	INW	PCE
20	215	456.5	49 59 03.3	77 37 38.5	28.11.1974	-	0.001-20	-	-	INW	PCE(ARS) Dynamic release of gaseous products through the emplacement well. 20 min after the explosion the levels of radiation in the epicenter reached 110 R/h. No residual contamination.
21	1003	-	49 59 30.2	77 38 06.9	14.10.1965	4 00 00.2	1.1	-	48	IE	ESO
22	2613	452.1	49 55 22.4	77 46 13.8	18.07.1979	3 17 04	0.001-20	5.2	-	INW	FCE
23	2691	456	49 56 47.5	77 41 25.0	19.03.1978	3 46 59	0.001-20	5.2	-	INW	FCE
24	2803	455.9	49 57 33.3	77 39 44.6	16.02.1979	4 04 00.5	0.001-20	-	-	INW	PCE

No.	Well No.	Actual Elevation, m	North latitude	Eastern longitude	Explosion date	Time (GMT), hours, minutes, seconds	Explosion power, kt	Explosion magnitude	Depth of the charge, m	Test goal	Radiation effect*
25	P-1, Lazurit	-	49 55 47.2	77 31 49.1	07.12.1974	05 59 57	1.7	4.7	75	IE	PCE

n/d.	no data
*INW	improvement of nuclear weapons / nuclear weapons development
TIC	test of industrial charges (to perform nuclear explosions for peaceful purposes)
IE	industrial nuclear explosions (holding the peaceful development of the technology);
PCE	partial camouflet explosion (rapid and dynamic outflow of radioactive gaseous and vaporous products, followed by ignition of the mixture)
PCE – ARS	partial camouflet explosion with abnormal radiological situation (explosion of total internal actions with abnormal radiological situation (ARS), accompanied by an early and dynamic pressurized getting of explosion products in the gas and vapour phase into atmosphere, due to accidental abnormalities in the normal process of testing or its consequences not predicted in the project: it could cause or lead to over-exposure of people or material damage)
FCE	full camouflet explosion (with explosion no inert gases went into the atmosphere)
ESO	explosion with soil outburst (blasting cone)
PIE(RIG)	partial internal explosion with a joining of fracture zones and spallation destruction of the surface in the epicentral area of the explosion and the vent, usually negligible, outflow of short-lived radionuclides into the atmosphere – inert gases)

It should be noted that the difference between the number of tests (24 tests) and known wells (25 wells) is caused by serial underground nuclear tests in the wells No. 109 and 2803 in 16.02.1979. It is also worth noting that the official sources are incomplete or provide false information about the UNE radiation effects. Thus, according to [1, 2, 4] the ejection of soil was accompanied by only a UNE conducted in well 1003 (the crater diameter by its rock piles is 280 m, pile height of 10 m). However, the surveys found that the soil ejections were accompanied by the UNEs in wells Nos. 101 and 125. In this case, at well 101, the crater is much larger than the crater of well 1003. Also at the well there is a crater 104 with a radius of up to 100 m, depth of 10 m. Near wells Nos. 110, 111, 131 and 215 within 150 m, on the contrary, there is an elevation of the ground up to 2 m.

According to [1, 2, 4] full camouflet explosions (FCE) were found at 7 wells (104, 105, 106, 107, 126, 2613 and 2691). The survey [3, 9] in near-mouth areas of these wells detected a significant radioactive contamination. In this connection, these wells can be classified as PCE (partial camouflet explosion). On the other hand, at emplacement wells Nos. 109, 110, 128 and 129 mentioned in [1, 2, 4] as PCE, the survey found no significant contamination. In this connection, these wells can be categorized as FCE.

1.2. Factors and mechanisms for formation of the radiation situation at "Sary-Uzen" site

At the most general level the radiation environment of any area can be represented as a superposition of two components:

1. Natural radioactivity of the environment.
2. Contamination with artificial radionuclides.

The natural sources of radiation include cosmic rays and natural radioactive material distributed on the surface and in the interior of the Earth. This issue is detailed in a number of works, such as [5] and not reviewed in the framework of this article.

For the study area due to the specificity of its geographical position, the contamination with artificial radionuclides in the first place will be determined by testing of nuclear weapons at the STS, which recover the following radionuclides:

- fission products – ^{137}Cs, ^{137}Ba, ^{147}Pm, ^{151}Sm, ^{90}Sr, ^{90}Y, ^{99}Tc;
- environment neutron activation products – ^{60}Co, ^{152}Eu, ^{154}Eu, ^{3}H, ^{14}C, ^{36}Cl;
- unreacted part of the charge – ^{238}Pu, $^{239+240}$Pu, ^{241}Pu, ^{241}Am, ^{3}H.

Traditionally, the following radionuclides are the most biologically important: ^{137}Cs, ^{90}Sr, ^{3}H, $^{239+240}$Pu.

The main potential sources of contamination for this territory are the consequences of the 50's and 60's surface nuclear explosions long-range fallouts, the effects of short-range fallout from the release of radioactive gases and aerosols in the tests in wells at "Sary-Uzen" site as well as blocks of rocks enclosing the central zones of the UNE.

1.2.1. Atmospheric radioactive fallout

The surface nuclear tests resulted in a high radioactive contamination of large areas and formed radioactive plumes stretching for hundreds of kilometers from the explosion epicenters.

According to [5] and [6], the "Sary-Uzen" site area is crossed by 4 radioactive plumes from the surface nuclear test conducted in 24.09.51 at "Experimental field" site as well as plumes from the model experiments (Figure 2).

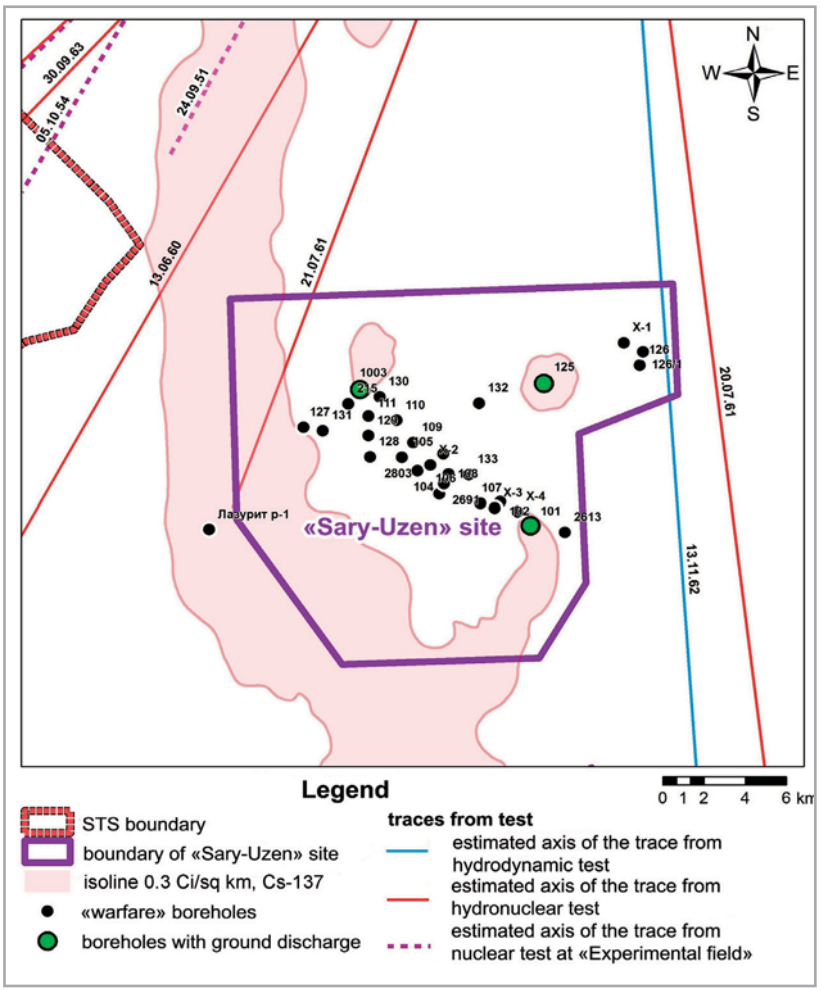


Figure 2. Relative positions of "Sary-Uzen" site and the test trace axes

In 1960, 1961, 1963 at the Semipalatinsk Test Site the USSR Ministry of Defense implemented a model (hydrodynamic and hydro-nuclear) experiments program. These experiments were also to study radionuclide α-activity fallout on the ground surface, determined by key nuclear materials that are part of the nuclear charge, mostly contamination by long-lived radionuclides such as plutonium-238, 239, 240 and uranium-238, 239. The "Sary-Uzen" is crossed by plume axes of two model experiments done in 1961 and 1962, which could have contaminated the surface with the above radionuclides.

The distance from the model experiments epicenter to the "Sary-Uzen" site is around 40 km. Such a distance is reached by the plumes from the hydro-nuclear tests of 21.07.1961 and hydrodynamic test of 1962.According to [7], the length of the zone contamination by the hydro-nuclear test with the level of activity density 0.1 μCi/m^2 > qα > 2,25*10^{-2} μCi/m^2 is 53 km (Table 2), and within the "Sary-Uzen" site the plume length may be about 8 km.

The length of the 13.11.1962 hydrodynamic tests fallout with an activity in the range of 1 to 0.1 μCi/m^2 is 86.5 km, and within the "Sary-Uzen" site the plume length to be around 6 km.

Table 2

Model experiments characteristics [7]

Test Date		21.07.61	13.11.62
q_1	L (km)	-	15.5
	S (km^2)	-	14
q_2	L (km)	17.5	86.5
	S (km^2)	17	375
q_3	L (km)	53	>100
	S (km^2)	149	(960)
Test type		hydronuclear	Hydrodynamic

Note:
— – no data
q_1 – activity density>1 μCi/m^2
q_2 – activity density>0,1 μCi/m^2
q_3 – activity density>2,25*10^{-2} μCi/m^2
L – contamination zone length
S – contamination zone area

Thus, all of the above mentioned surface tests can be considered as the most likely sources of contamination of the study area.

1.2.2. Local contamination of the UNE epicentral zones at "Sary-Uzen" site

Based on the data about the radiation effect during the underground nuclear tests, the site area contamination was caused by radiation emergency situation that had occurred during the testing of nuclear devices in the wells No. 101, 111 and 215, as well as during the excavation explosions in the wells No. 1003 and No. 125.

The local soil contamination lies on the surface within the epicentral zones formed mainly as a result of the short-range fallout effects from the release of radioactive gases and aerosols from the nuclear tests in the emplacement wells. The aero-gamma-survey detected local radioactive fallout traces around wells No. 1003 and 125, as well as longer (over 10 km) radioactive fallout trace from the tests in well 101.

Character of artificial radionuclides' distribution of in the surface soil is described in the chapter 2.1.

The geotechnical conditions of the UNEs at "Sary-Uzen" site is largely similar to the conditions at "Balapan" site. In this connection, the mechanism of radionuclides migration

from the rocks into groundwater at sites "Sary-Uzen" and "Balapan" is similar and described in detail in [8].

1.2.3. Contamination of surface soils due to global atmospheric fallout

Nowadays, almost anywhere on our planet one can detect radioactive contamination of the environment caused by various nuclear tests, accidents at nuclear power plants.

The fact of the matter is that during the atmospheric nuclear tests the considerable part of radioactive products is released into the stratosphere. Microscopic size radioactive aerosols (~ $4*10^{-5}$ cm) in the cloud retain in the stratosphere from a few months to several years, and winds carry a cloud over all the earth (stratospheric transfer).

Artificial radionuclides from the atmosphere with precipitation and dry fallout reach the surface layer of the soil. The density of this so-called global fallout depends on the geographical latitude, the time elapsed after the release of artificial radionuclides into the atmosphere, the season and the meteorological factors [7].

After coming into effect of the Treaty 1963, banning nuclear tests in the atmosphere, in outer space and under water, the radioactivity of the atmosphere has been progressively reduced and thus far has fallen a hundred times. The short increase in radioactive contamination of the Earth's atmosphere over the last decade was registered in 1986 as a result of the accident at the Chernobyl Nuclear Power Plant [7].

The calculations [7] showed that the specific activity of global fallout for 2010 is: ^{137}Cs – 15,2 Bq/kg; ^{90}Sr – 9,4 Bq/kg; ^{151}Sm- 1,2 Bq/kg and ^{99}Tc – 0,2 Bq/kg.

2. PRESENT RADIOECOLOGICAL STATUS AT "SARY-UZEN" SITE

2.1. Radioactive contamination of soil at "Sary-Uzen" site and surrounding area

2.1.1. Medium-scaled (1 : 200 000, 1 : 100 000) radiological research findings

2.1.1.1. Basic methodology

The medium-scaled (1:200,000) radiological investigations around "Sary-Uzen" site were conducted to clarify the positions of contaminated spots of the area, where in the future it is necessary to conduct a more detailed (large-scaled) research. The surveyed territory was within "Sary-Uzen" site and beyond in the north-west, north and north-east directions. The area is over 500 km^2.

The medium-scaled areal radiological studies (Figure 3) were to measure the radiation parameters and soil sampling within 2*2 km grid. To study radionuclides distribution in the soil depth, additionally at 10 points soil was sampled layer-wise at 5 cm spacing to a depth of 15 cm from the same pits as the main sample. The distribution of radionuclides at a depth in soil cuts was studied in locations evenly spaced across the study area.

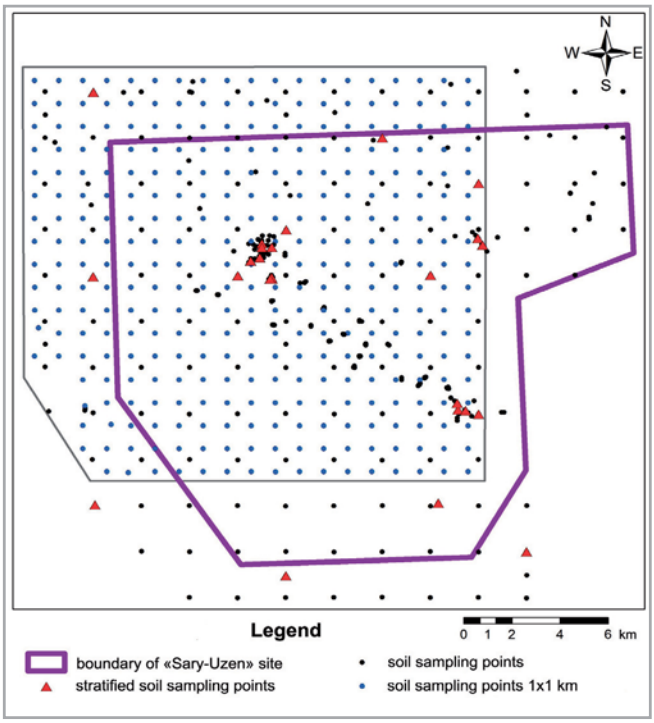


Figure 3. Soil sampling points arrangement at medium scaled survey

Medium-scaled (1:100,000) radiological studies were conducted in the western part of the STS, covering about 80 % of "Sary-Uzen" site area (Figure 3). The areal radiological survey was carried out at fixed points on a regular grid of 1*1 km, offset from the survey grid with a scale 1: 200 000 on 500*500 meters (about 700 meters in distance). At each point of the survey soil was sampled and equivalent dose rate (EDR) of gamma-radiation was measured on the surface of soil at a height of 1 m.

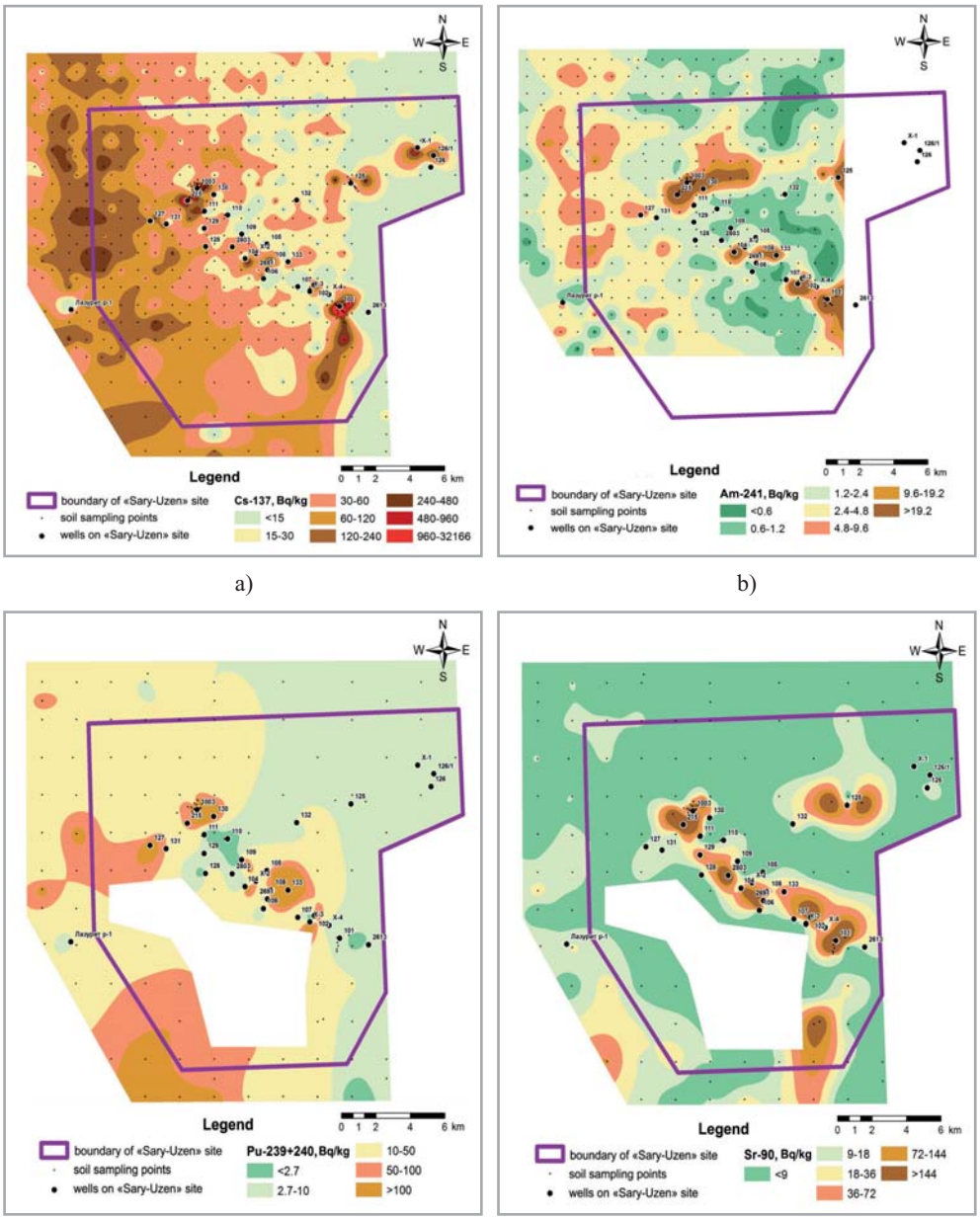
2.1.1.2. Results and discussion

The radiation parameter measurements showed that the density of α- and β-particles is at background level and is not higher than the instrumental detection limit 0.5 and 10 part./ (min * cm^2), respectively. The EDR range was: on the soil surface – 0.1-0.23 μSv/h, at a height of 1 m – 0.1-0.21 μSv/h, which is slightly higher than the background for the STS equal to 0.13 – 0.15 μSv/h.

The laboratory tests enabled to construct distribution maps of radionuclides ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}Pu$ with in the surveyed area (Figure 4 a, b, c, d) [9].

Areal activity of ^{137}Cs in 45 % of the surveyed points is higher than background of global fallout, equal to ~65 m Ci/km^2 (15 Bq/kg), in other cases, is at or below the background. Areal activity of ^{90}Sr in 30 % of the surveyed points is above the background of global fallout equal to ~ 39 m Ci/km^2 (9 Bq/kg). In almost all samples of soil $^{239+240}Pu$ spe-

cific activity exceeds the background of global fallout constituting 0.55-2.67 Bq/kg (up to ~ 12 m Ci/km^2). Maximum excess is up to 52 times [10].



a) b)

c) d)

Figure 4. Radionuclide distribution at Sary-Uzen site a) ^{137}Cs, b) ^{241}Am, c) ^{90}Sr, d) $^{229+240}$Pu

The maximal amounts of these radionuclides were registered in the southern, south-western and western parts of the study area. The contaminated areas of the territory coincide with the radioactive fallout trace from the 24.09.1951 test, and heads of wells Nos. 1003, 101, 125, 215. Also there are elevated radionuclides concentrations in near-mouth areas of other wells. The elevated levels of radionuclides in the near-mouth areas of the wells are caused by the release of nuclear explosions products to the surface. The contamination in the near-mouth areas will be discussed in detail later on.

Assessment of the radionuclide in-depth distribution in the soil

Analyzes were conducted in order to study ^{137}Cs in-depth distribution. ^{137}Cs distribution feature is that the maximal concentration is in the upper 5 cm layer, and then dramatically declines in activity at lower layers (Figure 5). The data on ^{137}Cs in-depth distribution are consistent with the previous STS studies [7].

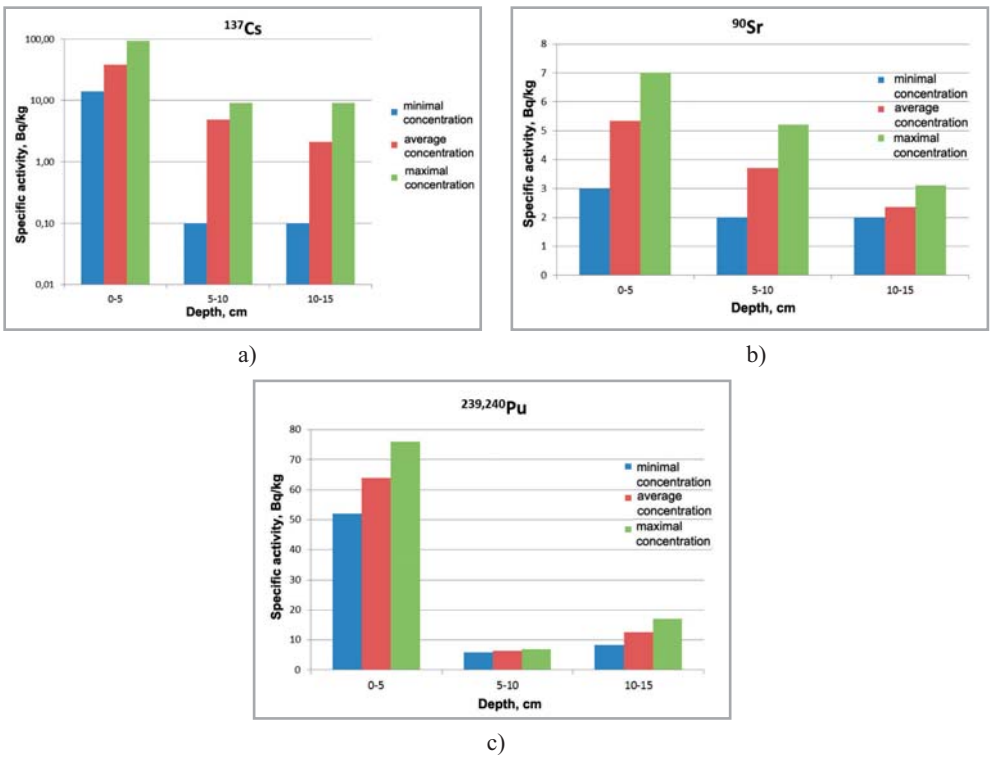


Figure 5. In-depth distribution of a) ^{137}Cs, b) ^{90}Sr, c) $^{239+240}$Pu in soil profile

For laboratory analysis, to determine ^{90}Sr and $^{239+240}$Pu in layer-wise soil samples, we chose three profiles from five soil profiles located in the contaminated area. Although specific activity of ^{90}Sr decreases with depth, but there is no sharp decline in activity.

Study of the radionuclide in-depth distribution showed that ^{90}Sr is distributed in the soil profile more uniformly, unlike ^{137}Cs and $^{239+240}$Pu. The considerable amount of ^{90}Sr in the lower layer (10-15 cm) confirms its high migration capacity, and also implies the presence of

this radionuclide in the deeper layers of the soil profile. The distribution pattern of $^{239+240}$Pu is identical to the distribution of ^{137}Cs.

2.1.2. Levels of radioactive contamination of soils within the near-mouth areas of "Sary-Uzen" site emplacement wells

The UNEs at "Sary-Uzen" site caused the following consequences: abnormal radiological situations occurred in wells Nos. 101, 111 and 215. In wells Nos. 1003, 101 and 125 the nuclear tests were accompanied by soil ejection, in 14 wells – partial camouflet explosion, in 7 wells – full camouflet explosion. The underground nuclear test locations can be classified as potential radiation hazardous facilities. In this connection, in 19 near-mouth areas of the emplacement wells, 13 points were surveyed for a preliminary assessment of the radiation situation. A more detailed examination was carried out at wells where the UNEs were accompanied by ARS and soil ejection.

The survey of 13 points was preliminary. Using this scheme, at "Sary-Uzen" site surveys were carried out at emplacement well near-mouth areas: Nos. 102, 104, 105, 106, 107, 108, 109, 110, 126, 127, 128, 129, 130, 131, 132, 133, 215, 2613, 2691, 2803 and 4 unknown wells: X-1, X-2, X-3, X-4, "daisy" (Figure 6).

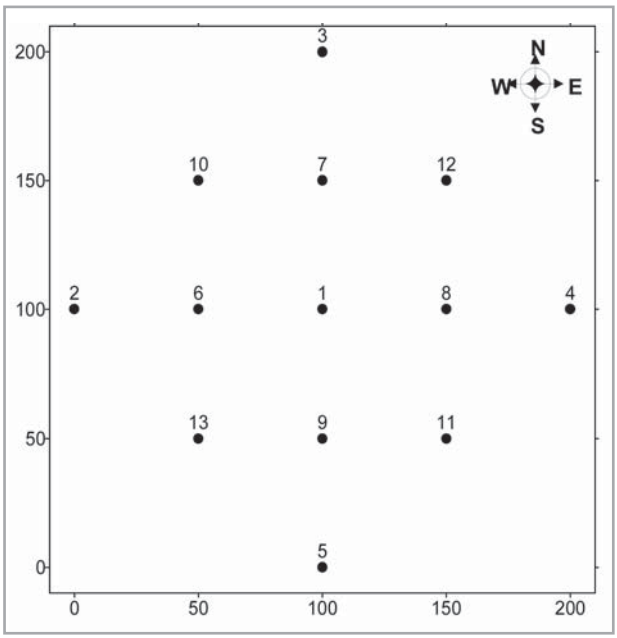


Figure 6. Well survey layout at "Sary-Uzen" site

At each survey point we measured β-particle flux density, equivalent dose rate (EDR) of gamma radiation on the soil surface and at a height of 1 m. Soil was sampled at near-mouth area: near the well head and at point with the highest radiation parameters. If radioactive contaminated spot was detected outside soil sampling grid, additionally a point with maximum

contamination was sampled. Satellite navigation devices were used in order to determine the coordinates of the soil sampling points.

To clarify the radiation environment at wells Nos. 101, 125 and 1003 we conducted an additional radiological examination, which consisted of measurements of β-particles flux density, equivalent dose rate of gamma radiation on the soil surface along the profile passing through the center of the crater on the map below (Figure 7). The ends of the profile are located outside the contaminated area, delineated by measurements of EDR. At each point of the profile a spot sampling of soil was done, at 2 points on each well – layer-wise soil sampling to a depth of 30 cm with 5 cm spacing.

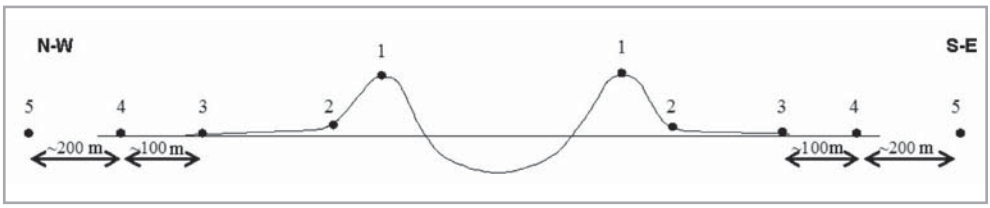


Figure 7. Arrangement of profiles at wells № 125 and No.1003

Below are photos of generic arrangement of the emplacement wells, EDR distribution and β-particles flux density schematic-map, as well as laboratory analyzes results on soil samples composition and concentration of radionuclides.

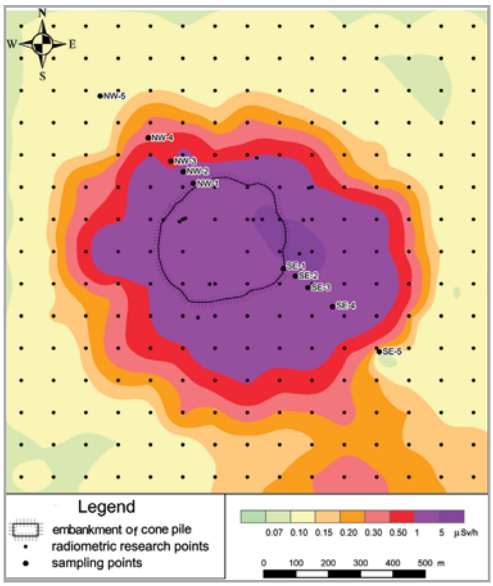
The discrepancy in the specific activities of some artificial radionuclides in the soil at primary and repeated surveys is explained by different depths (5 and 10 cm) of soil sampling, and when re-surveying the point of sampling may have been spaced from the previous by 10-15 meters, which was caused by an error of positioning.

Well 101

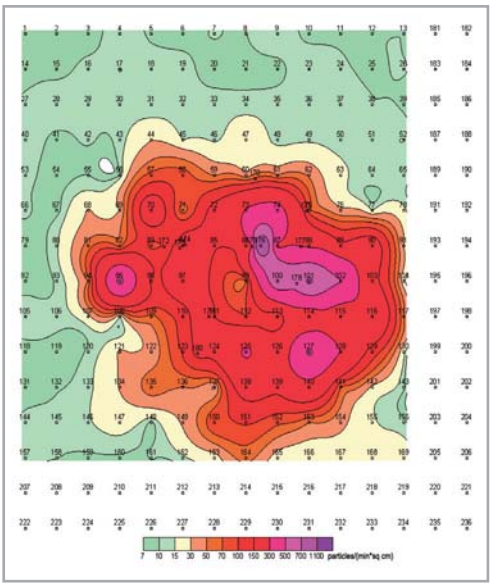
Well 101 is located in the western part of "Sary-Uzen" site. Currently, at well 101 a crater formed with a diameter of 350-400 m and a height of piles ~ 10-15 m. The area around the crater is mostly flat, poorly changed after the explosion (Figure 8). The bottom of the crater is filled with water.

Figure 8. Well 101. Overview of the well mouth

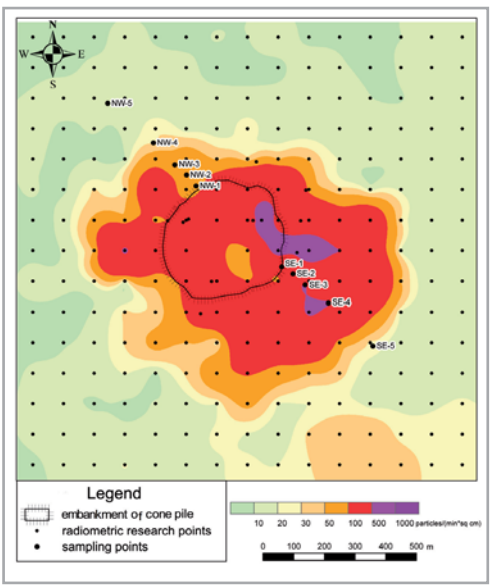
The results of radiological survey is mapped on a diagram (Figure 9 a, b, c), as well as in Table 3.



a)



b)



c)

Figure 9. Well 101. Schematic map of a) EDR; b) alpha-particles flux density; c) beta particles flux density

Table 3.

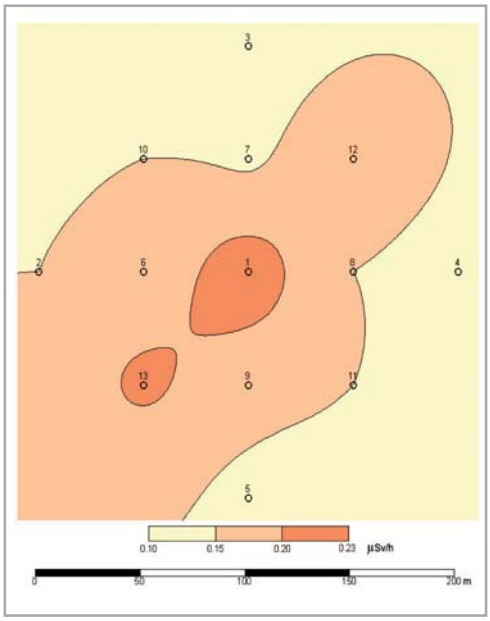
Results of laboratory tests of soil from well 101 area

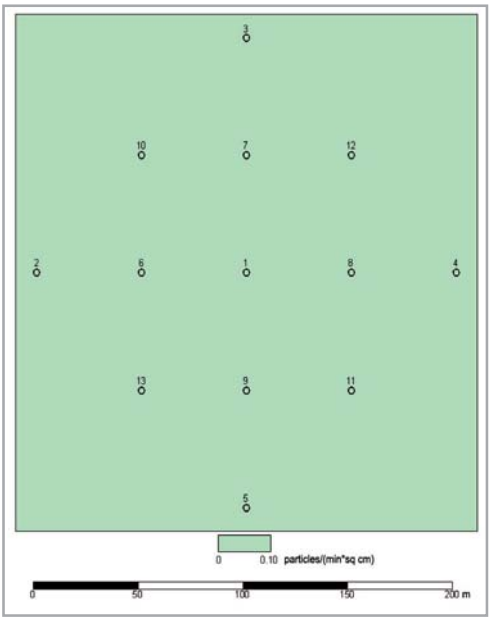
Point	Sampling date	Depth, cm	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{154}Eu, Bq/kg	^{90}Sr, Bq/kg
S1	25.08.2006	0-5	30±10	13±10	400±130	6 250±40	640±10	1 220±30	470±20	6 010±930
S2	25.08.2006	0-5	10±6	10±6	370±120	3 980±30	640±10	1 200±30	480±20	4 200±700
S2	25.08.2006	5-10	<0,6	<0,8	-	4 970±30	620±10	1 140±30	440±20	6 300±1 000
S2	25.08.2006	10-15	<0,6	<0,8	-	7 900±50	900±20	1 520±50	660±30	5 880±905
S2	25.08.2006	15-20	<0,6	<0,8	-	12 150±20	950±20	1 580±60	690±30	6 790±1 020
S2	25.08.2006	20-25	<0,6	<0,8	-	4 930±30	250±10	420±30	200±10	1 090±280
S2	25.08.2006	25-30	<0,6	<0,8	-	4 020±30	110±5	170±30	70±10	1 730±370
S3	25.08.2006	0-5	7±6	23±20	920±25	9 170±60	1 610±30	2 960±60	1 240±50	11 530±1570
S4	25.08.2006	0-5	15±7	16±7	230±90	3 700±30	420±10	800±30	340±20	4 810±770
S5	25.08.2006	0-5	30±5	26±5	-	36±4	-	-	-	<100
1	25.08.2006	0-5	30±10	20±10	80±10	1 560±20	140±10	260±20	80±10	1 740±380
2	25.08.2006	0-5	30±10	30±10	230±15	3 340±40	350±10	560±30	220±20	2 950±540
2	25.08.2006	5-10	60±10	40±10	50±7	1 200±20	80±7	130±10	47±10	1 750±370
2	25.08.2006	10-15	30±5	24±5	-	200±10	5±2	12±5	2,7±2,4	870±270
2	25.08.2006	15-20	30±5	20±4	-	110±6	7±2	10±5	8±6	180±140
2	25.08.2006	20-25	30±4	20±4	30±4	120±6	8±2	13±6	4±3	180±140
2	25.08.2006	25-30	30±5	20±5	5±3	110±7	10±3	14±5	2±1	132±130
3	25.08.2006	0-5	16±8	20±7	70±10	1 560±20	120±10	150±16	70±10	1 140±300
4	25.08.2006	0-5	25±4	14±3	-	490±10	20±3	30±7	10±5	1 060±300
5	25.08.2006	0-5	30±5	20±4	-	10±2	-	-	-	-
"-" no measurement performed										

Well 102

Well 102 is located in the western part of the test area "Sary-Uzen" site. Currently, around well 102 the daily soil surface is smooth, no post-explosion alteration seen, well head destroyed, casing removed (Figure 10 a). The results of radiological survey are mapped on a diagram (Figure 10 b, c), as well as in Table 4.

a)





b) c)

Figure 10. Well 102: a) general view of the mouth;
b) EDR distribution map; c) β-particle flow density

Table 4.

Results of laboratory tests of soil from well 102

Point	Sampling date	Depth	Notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{154}Eu, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	mouth	30±6	30±7	70±10	1 400±20	10±5	35±4	12±3	1 000±180	300± 66
A	18.09.2004	0-10	Maximal contamination point	50±10	6±3	-	100± 10	-	-	-	4 800±700	2±1
1	15.09.2006	0-5	mouth	10±4	14±6	-	3 560±18	5±1	15±8	10±3	2 200±430	-
13	15.09.2006	0-5	Maximal contamination point (same as "A")	30±3	26±3	-	80±3	-	-	-	<100	-
"-" no measurement performed												

Well 104

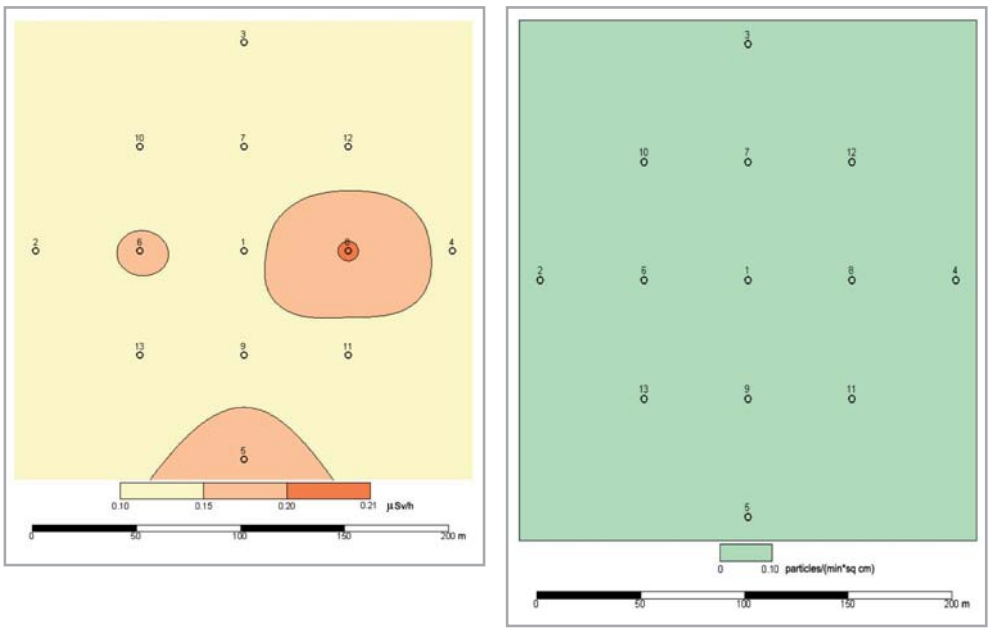
Well 104 is located in the western part of "Sary-Uzen" site. At present, there is a great a crater at the mouth of the well with diameter of 100-130 m, depth of 10 m. To the south side of the crater there is a small swelling of the relief (Figure 11 a). The crater of well 104 is filled with water. The results of radiological survey are mapped on a diagram (Figure 11 b, c), as well as in Table 5.

Table 5.

Results of laboratory tests of the soil from well 104

Point	Sampling date	Depth	Notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{154}Eu, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	15.10.2004	0-10	mouth	40±10	30±10	-	20±6	-	-	-	14±4	6±2
A	15.10.2004	0-10	Maximal contamination point	30±10	30±4	380± 24	8240± 40	320± 26	260± 10	100± 40	697± 130	1760± 390
1	15.09.2006	0-5	mouth	26±3	20±2	-	10±1	-	-	-	-	-
8	15.09.2006	0-5	Maximal contamination point (same as "A")	33±3	30±3	-	16±2	-	-	-	40±6	7±2
"-" no measurement performed												

a)



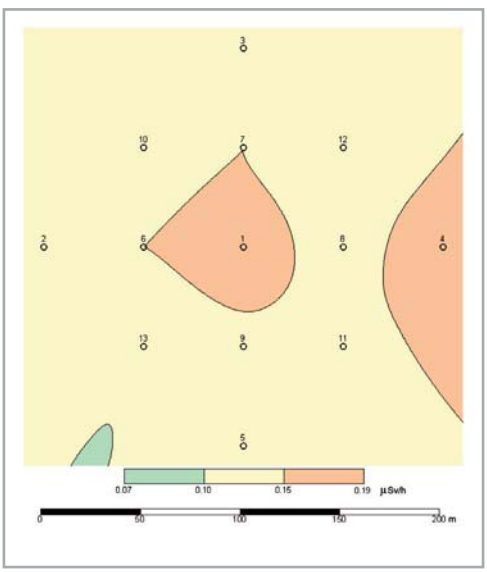
b) c)

Figure 11. Well 104: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

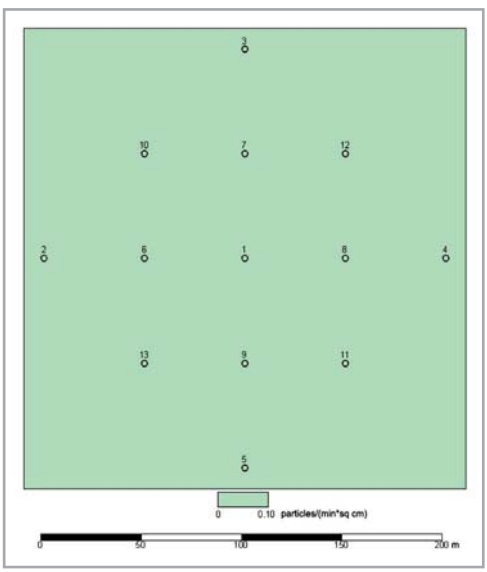
Well 105

Well 105 is located in the central part of "Sary-Uzen" site. Currently, there is a crater at the well mouth with a diameter of 120 m, a depth of 3.0 m, head removed, and an excavation with a diameter of about 8 m and a depth of 2-3 m (Figure 12 a). The results of radiological survey are mapped on a diagram (Figure 12 b, c), as well as in Table 6.

a)



b)



c)

Figure 12. Well 105: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Table 6.

Results of laboratory tests in vicinity of the well 104

point	Sampling date	Depth	notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	mouth	70±10	90±10	7±3	7±3	6±2
A	18.09.2004	0-10	Maximal contamination point	30±4	25±3	10±2	8±2	2±1
1	14.09.2006	0-5	mouth	30±3	20±2	2±1	-	-
4	14.09.2006	0-5	Maximal contamination point (same as "A")	30±3	20±2	30±2	6±2	80±15
"-" no measurement performed								

Well 106

Well 106 is located in the central part of "Sary-Uzen" site. Currently the post-explosion alteration on the relief is minor. Well head destroyed, casing cut, near the mouth is a rectangular excavation: side length is up to 4 meters, depth is up to 4 meters (Figure 13 a). The results of radiological survey are mapped on a diagram (Figure 13 b, c), as well as in Table 7 below.

Table 7.

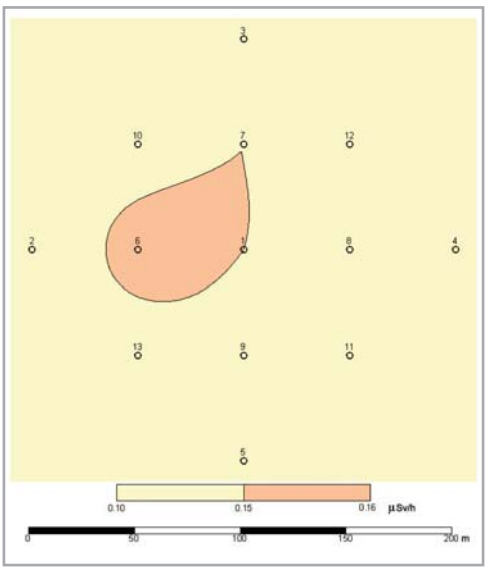
Results of laboratory tests of soil from well 106

point	Sampling date	Depth	notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	15.10.2004	0-10	mouth	10±5	40±10	8±2	6±3	6± 2
A	15.10.2004	0-10	Maximal contamination point	50±10	50±10	550± 16	3600± 610	30±7
1	14.09.2006	0-5	mouth	27±3	30±3	<0,5	-	-
6	14.09.2006	0-5	Maximal contamination point (same as "A")	30±3	20±2	30±2	<100	5±1
"-" no measurement performed								

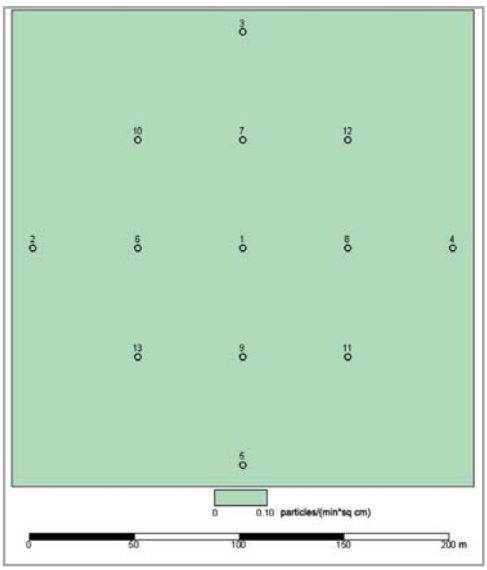
Well 107

Well 107 is located in the central part of "Sary-Uzen" site. Currently the area around the well is slightly raised, there are post-explosion deformation in the form of concentric ridges up to 0.5 m. Well head destroyed, casing is cut, there is an excavation with a diameter of 6 meters, a depth of 3 meters near the mouth (Figure 14 a). The results of radiological survey are mapped on a diagram (Figure 14 b, c), as well as in Table 8.

a)



b)



c)

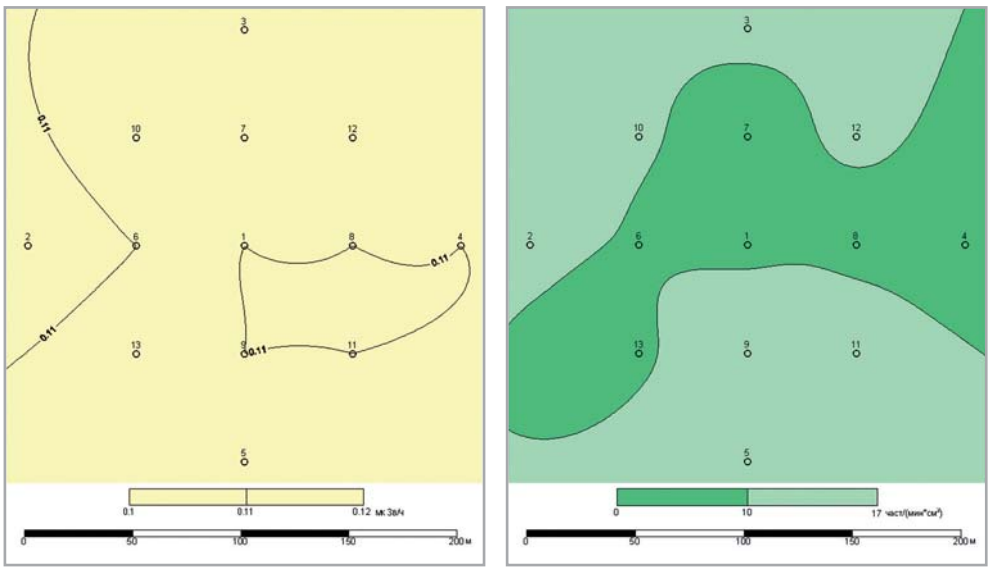
Figure 13. Well 106: a) general view on the mouth; b) EDR distribution map; c) β-particle flow density

Table 8.

Results of laboratory tests of soil from well 107

Point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.08.2006	0-5	26±4	25±4	1±0,2	50±10	-
5	18.08.2006	0-5	20±3	20±3	12±2	4±2	10±2

a)



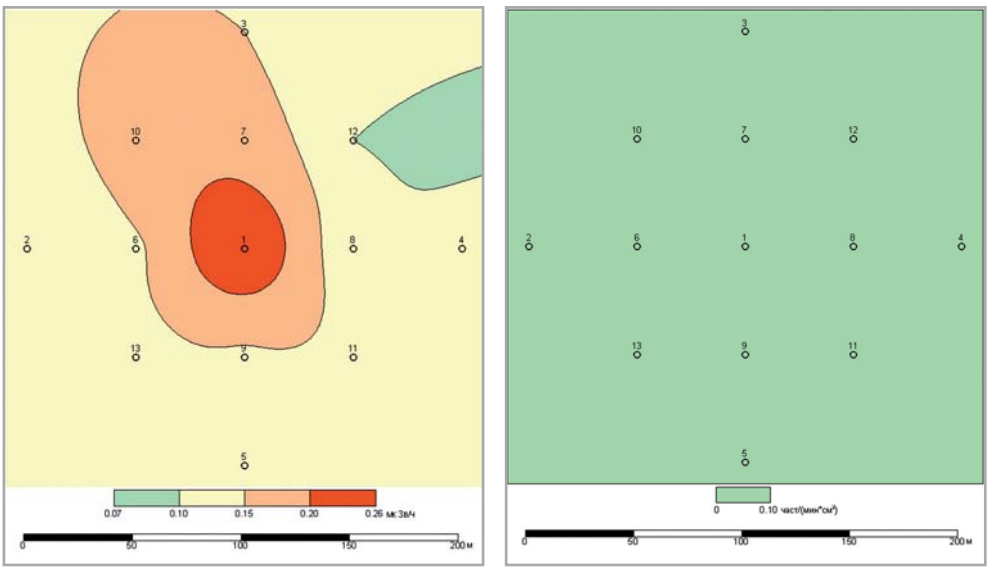
b) c)

Figure 14. Well 107: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Well 108

Well 108 is located in the central part of "Sary-Uzen" site. Currently, the post-explosion alteration on the Earth's surface is insignificant. There is an elevation of the soil in the well mouth area. Well head destroyed, casing completely dismantled, near the mouth there is an excavation with a diameter of 5 meters and a depth of 3 meters (Figure 15 a). The results of radiological survey are mapped on a diagram (Figure 15 b, c), as well as in Table 9.

a)



b) c)

Figure 15. Well 108: a) overview of well mouth, well mouth, excavation depth is about 4-5 m; b) EDR distribution map; c)beta particles flux density

Table 9.

Results of laboratory tests of soil from well 108

point	Sampling date	Depth	notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{154}Eu, Bq/kg	^{90}Sr, Bq/kg
1	02.09.2004	0-10	mouth	30±6	20±8	70±11	2100±20	20±3	56±5	16±1	-
1	14.09.2006	0-5	mouth	30±4	16±3	-	1720±14	27±2	100±10	30±4	4000± 670
7	14.09.2006	0-5	Maximal contamination point	40±4	20±4	-	410±6	-	-	-	5900± 910
"-" no measurement performed											

Well 109

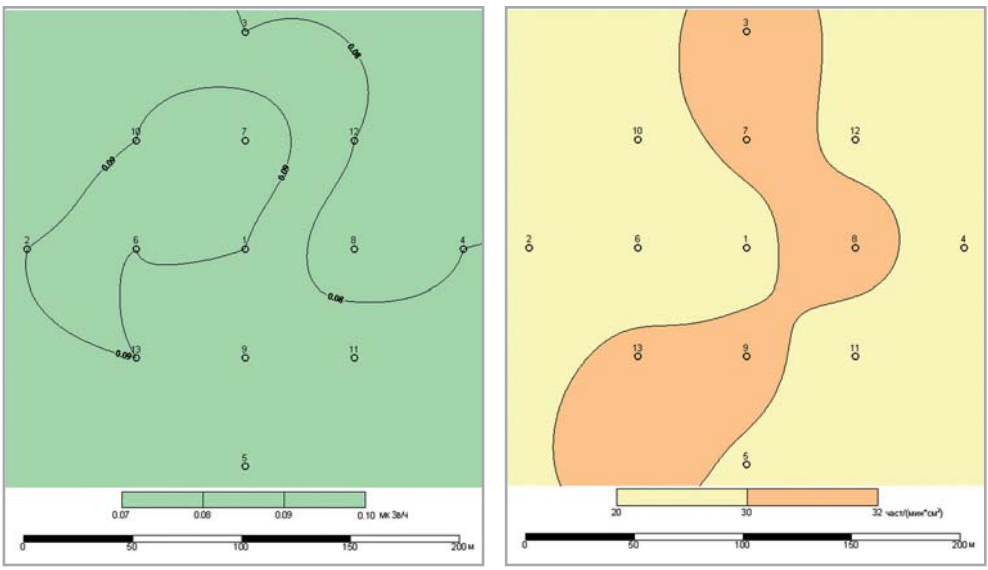
Well 109 is located in the central part of "Sary-Uzen" site. Currently the post-explosion alteration in the Earth's surface is minor, there are shallow dips and a slight swelling of the relief. Well casing is completely dismantled, excavation in the form of a 3x3 meters square with a depth of 3 meters (Figure 16 a). The results of radiological survey are mapped on a diagram (Figure 16 b, c), as well as in Table 10.

Table 10.

Results of laboratory tests of soil from well 109

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	13.04.2006	0-5	30±3	30±3	5±1	16±4	-
1	18.08.2006	0-5	40±4	20±3	7±1	100±20	10±2
7	18.08.2006	0-5	40±5	20±4	3±1	-	-
"-" no measurement performed							

a)



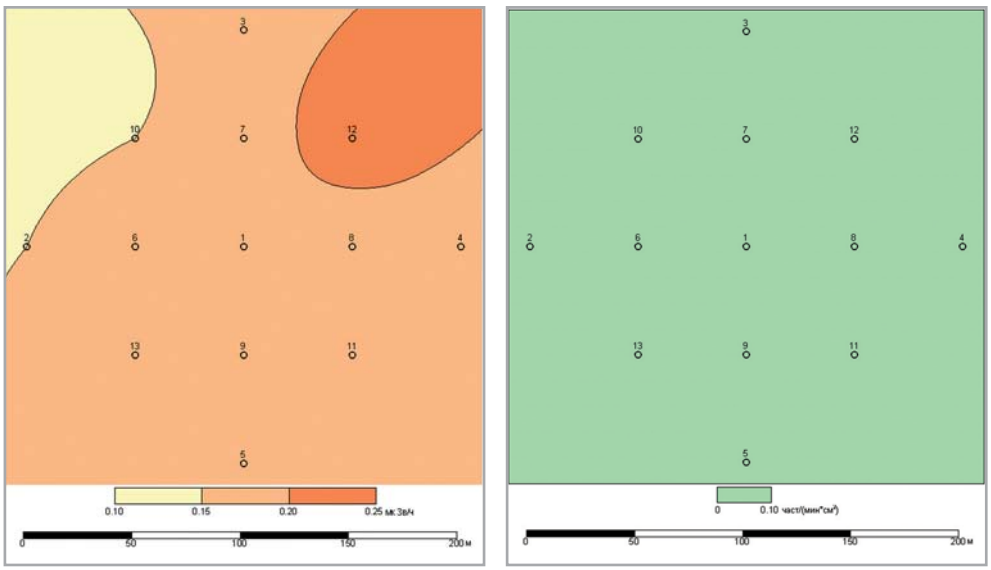
b) c)

Figure 16. Well 109: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Well 110

Well 110 is located in the central part of "Sary-Uzen" site. Currently, around the well within 100-150 m is a 2-2.5 m high surface elevation, well casing is dismantled at a depth of 6 m, near the mouth is an excavation in the form of a square (Figure 17 a). The results of radiological survey are mapped on a diagram (Figure 17 b, c), as well as in Table 11.

a)



b) c)

Figure 17. Well 110: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Table 11

Results of laboratory tests in vicinity of the well 110

point	Sampling date	Depth	notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	mouth	40±10	30±10	26±5	10±3	2±1
A	18.09.2004	0-10	Maximal contamination point	60±10	40±10	2±1	10±3	1±0,5
1	14.09.2006	0-5	mouth	20±2	24±2	50±3	10±3	3±1
12	14.09.2006	0-5	Maximal contamination point (same as "A")	40±3	20±2	7±1	-	-
"-" no measurement performed								

Well 111

Well 111 is located in the northern part of "Sary-Uzen" site. Currently, the ground around the well raised by 2-2.5 m within 150-200 m from the well mouth. On the eastern side of the well mouth is swelling relief, head and casing removed (Figure 18). The results of radiological examinations are available in Table 12.

Figure 18. Well 111.Overview of well mouth

Table 12.

Results of laboratory tests of the soil from well 111

Point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	15.10.2004	0-10	30±7	30±10	3780±30	20±5	14±3
6	15.10.2004	0-10	30±5	26±4	2080±20	12±4	70±15

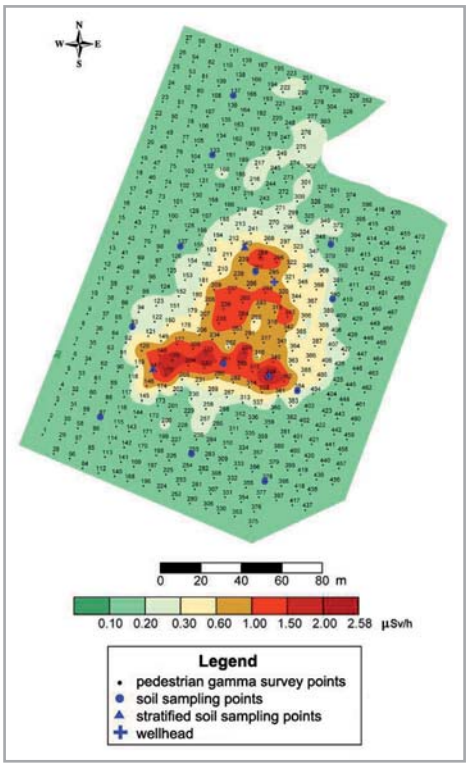
Radiological survey of well 111 in 2008

As a result of areal radiological survey of the well No. 111 mouth area the EDR was measured at 472 points. The EDR measurements were made on the soil surface and at a height of 1 meter. The survey grid was 10x10 m. The measured range is:

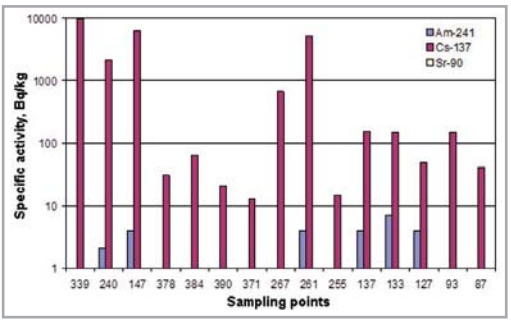
- EDR on the earth surface – from <0.10 to 2.58 μSv/h;
- EDR at a height of 1 m – from <0.10 to 1.98 μSv/h.

EDR distribution and soil sampling points scheme at the study area are provided in Figure 19 a.

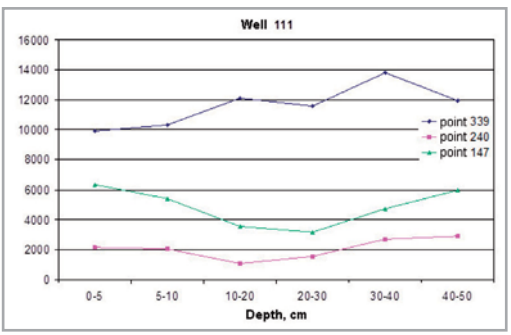
Around well No. 111 the distribution of radionuclides in the upper soil layer is shown in Figure 19 b.



b)



a)



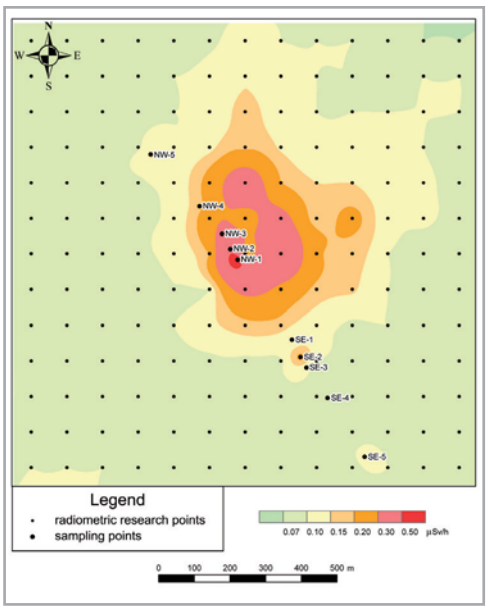
c)

Figure 19. Well 111: a) Distribution of EDR and soil sampling points in the surveyed area; b) distribution of radionuclides in the upper soil layer; c) in depth distribution of ^{137}Cs in soil horizon

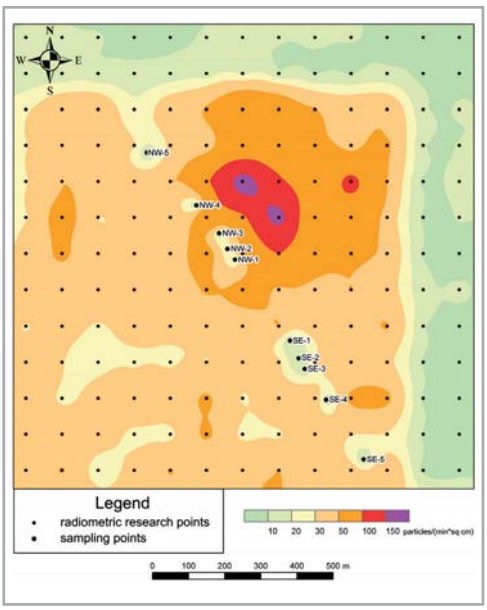
Well 125

Well 125 is located in the north-western part of "Sary-Uzen" site. Currently at the well mouth is a crater with a diameter of 250-300 m (height of heap up to 10-15 m). The bottom of the crater is filled with water (Figure 20 a). The results of radiological survey are mapped on a diagram (Figure 20 b, c), as well as in Table 13.

a)



b)



c)

Figure 20. Well 125: a) general view on the mouth; b) EDR distribution map; c) β-particle flow density

Table 13.

Results of laboratory tests of the soil from well 125

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{154}Eu, Bq/kg	^{90}Sr, Bq/kg
N1	03.11.2006	0-5	20±3	20±3	300±30	380±6	140±4	35±6	10±3	330±160
N2	03.11.2006	0-5	20±4	20±4	-	320±6	160±5	24±5	7±3	220±140
N2	03.11.2006	5-10	24±4	25±5	230±40	307±7	185±6	25±8	20±5	160±130
N2	03.11.2006	10-15	17±3	30±4	210±40	320±6	210±5	35±6	15±4	440±180
N2	03.11.2006	15-20	20±5	20±4	320±60	380±7	210±5	40±7	14±4	330±160
N2	03.11.2006	20-25	24±4	20±4	260±40	460±7	210±5	30±6	14±4	350±170
N2	03.11.2006	25-30	19±3	15±3	-	210±5	10±2	-	-	<100
N3	03.11.2006	0-5	25±4	24±4	-	510±7	160±5	-	-	340±160
N4	03.11.2006	0-5	27±3	24±4	-	40±2	2±1	-	-	<100
N5	03.11.2006	0-5	18±3	20±3	-	50±2	-	-	-	<100
S1	03.11.2006	0-5	27±2	30±3	-	3±1	-	-	-	-
S2	03.11.2006	0-5	28±2	18±2	-	30±2	-	-	-	-
S2	03.11.2006	5-10	32±3	20±3	-	60±3	-	-	-	<100
S2	03.11.2006	10-15	36±3	20±3	-	7±1	-	-	-	-
S2	03.11.2006	15-20	29±3	20±2	-	1±0,2	-	-	-	-
S2	03.11.2006	20-25	34±3	14±2	-	<0,7	-	-	-	-
S2	03.11.2006	25-30	29±2	20±2	-	<0,7	-	-	-	-
S3	03.11.2006	0-5	29±3	20±3	-	50±3	-	-	-	<100
S4	03.11.2006	0-5	26±3	20±3	-	40±2	-	-	-	-
S5	03.11.2006	0-5	24±3	10±2	-	30±2	-	-	-	-
"-" no measurement performed										

Well 126

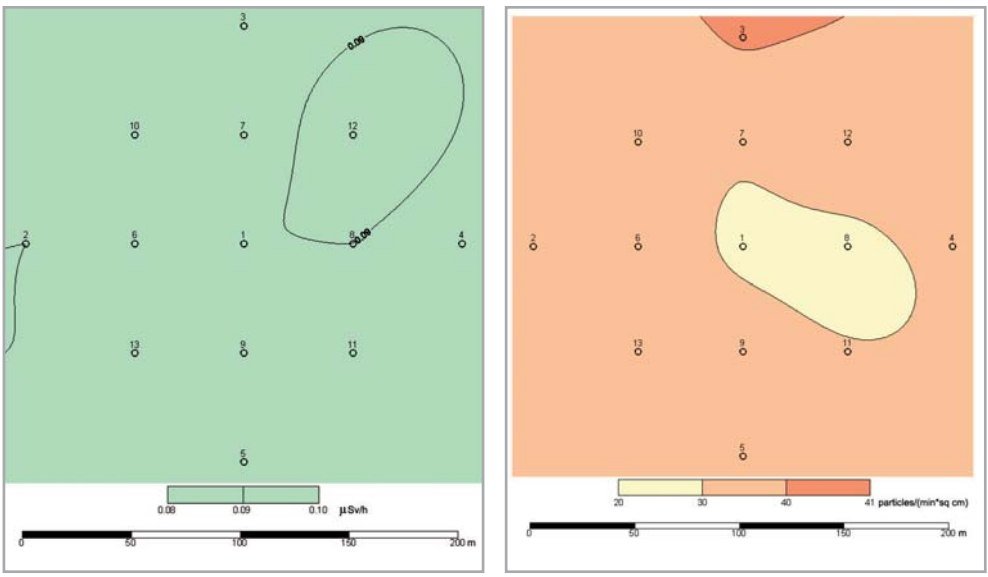
Well 126 is located in the north-western part of "Sary-Uzen" site. Currently, the relief near the well mouth is changed, there are buckling and failures. The casing is dismantled to a depth of 3 meters (Figure 21 a). The results of radiological survey are mapped on a diagram (Figure 21 b, c), as well as in Table 14.

Table 14.

Results of laboratory tests of the soil from well 126

point	Sampling date	Depth	notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	13.04.2006	0-5	Samples are taken 2.5-3m away from the buckling	30±3	30±3	8±1	30±7	-
1	18.08.2006	0-5	-	20±3	20±3	<1	-	-
3	18.08.2006	0-5	-	20±2	10±2	6±1	10	6±1
"-" no measurement performed								

a)



b) c)

Figure 21. Well 126: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Well 127

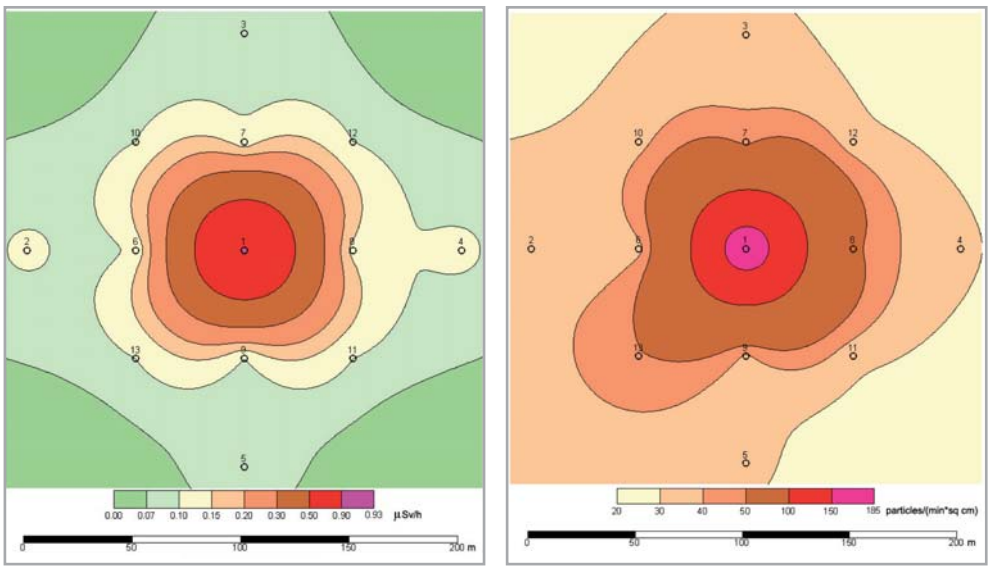
Well 127 is located in the north-western part of "Sary-Uzen" site.

Currently at the well mouth are two artificial dips to the south and west sides, the post-explosion relief has minor changes, well head destroyed, casing removed to a depth of 3 m (Figure 22).

a) b)

Figure 22. Well 127: a) overview of well mouth; b) well mouth.

In 2006, a radiological examination of the well near-mouth area was performed (Figure 23 a, b), (Table 15).



a) b)

Figure 23. Well 127: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Table 15.

Results of laboratory tests of the soil from well 127

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	12.05.2006	0-5	30±3	24±3	120±5	<100	-
1	18.08.2006	0-5	26±5	24±3	20400± 62	590±200	-
8	18.08.2006	0-5	30±6	40±6	50±4	20±5	300±60
"-" no measurement performed							

Well 128

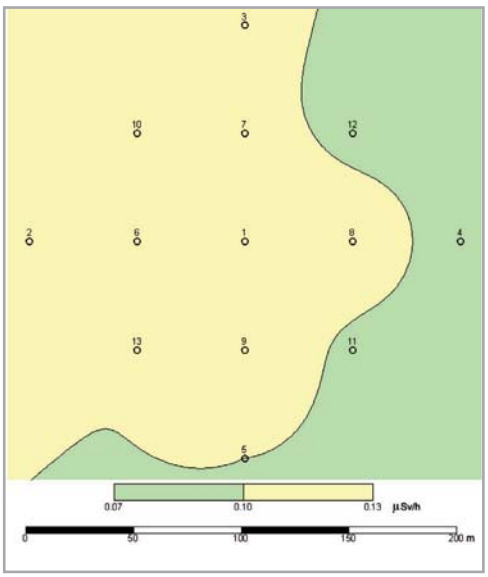
Well 128 is located in the central part of "Sary-Uzen" site. Currently at well mouth is a rising to 1 m. The well is banked and filled up, concreted cased pipe edge is visible out of the ground (Figure 24 a). The results of radiological survey are mapped on a diagram (Figure 24 b, c), as well as in Table 16.

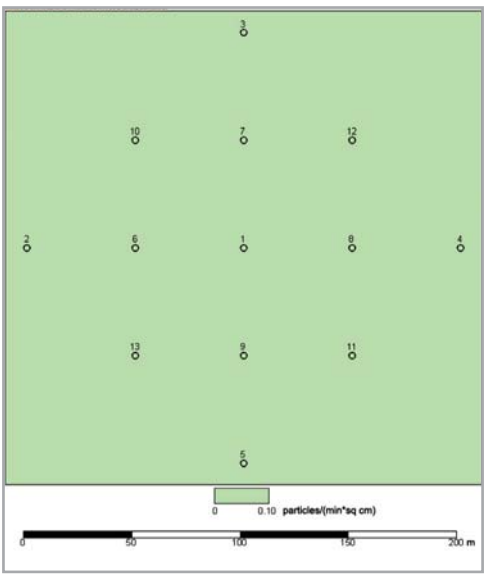
Table 16.

Results of laboratory tests of the soil from well 128

point	Sampling date	Depth	notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	mouth	10±2	40±12	40±6	4,0± 2,2	20±5
A	18.09.2004	0-10	Maximal contamination point	30±4	30±4	90±5	10± 3,5	50±12
1	13.09.2006	0-5	mouth	23±2	30±3	50±3	<100	-
6	13.09.2006	0-5	Maximal contamination point (same as "A")	30±3	50±3	76±3	<2	<1
"-" no measurement performed								

a)





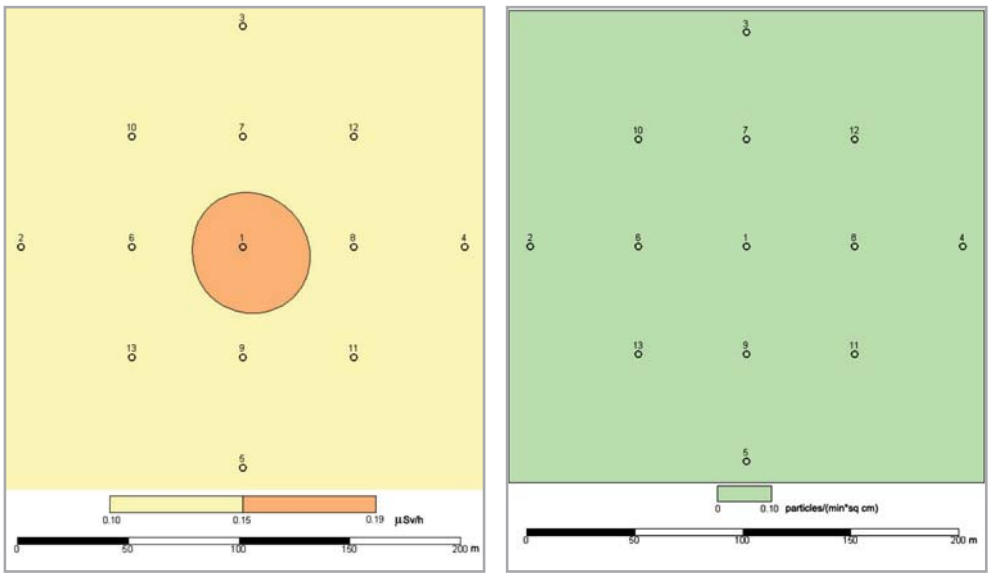
b) c)

Figure 24. Well 128: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Well 129

Well 129 is located in the central part of "Sary-Uzen" site. Currently, near the well mouth is a low (up to 1.5 m) elevation. In the east, 3 meters from the well mouth is a small crater. The well head destroyed, casing is cut off. An excavation to a depth of 6 m (Figure 25 a). Results of the radiological examination [9] can be found on a map diagram (Figure 25 b, c), as well as in Table 17.

a)



b) c)

Figure 25. Well 129: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

Table 17.

Results of laboratory tests of the soil from well 129

Point	Sampling date	Depth	Notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	mouth	40±12	26±11	6±4	-	-
9	18.09.2004	0-10	Maximal contamination point	30±9	20±10	30±5	-	-
1	13.09.2006	0-5	mouth	30±2	20±2	12±1	-	-
8	13.09.2006	0-5	Maximal contamination point	20±3	23±3	46±3	140± 25	9±2
"-" no measurement performed								

Well 130

Well 130 is located in the northern part of "Sary-Uzen" site. Currently there is a slight post-explosion alteration of the relief around the well mouth. On the east side, 10 meters from the well mouth is a crater with water. The well head destroyed, casing is cut off. A pit with a diameter of 4 meters and a depth of 3 meters (Figure 26 a, b) [9]. The results of radiological survey are mapped on a diagram (Figure 27), as well as in Table 18.

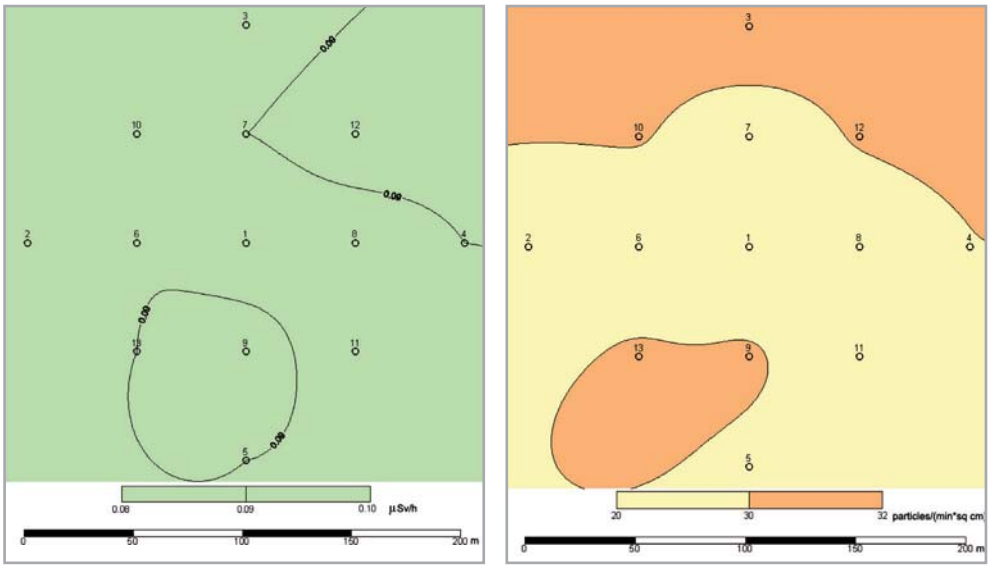
Table 18.

Results of laboratory tests of the soil from well 130

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	13.04.2006	0-5	30±2	30±3	-	40±2	<100	-
1	18.08.2006	0-5	35±4	30±4	-	<1	<2	-
3	18.08.2006	0-5	30±5	40±5	120±40	50±3	40±10	700±160
"-" no measurement performed								

a) b)

Figure 26. Well 130: a) overview of the well mouth; b) failed crater 10 m to the East



a) b)

Figure 27. Well 130: EDR distribution map (a) and β-particle flow density map (b) at the near-mouth site of Well 130

Well 131

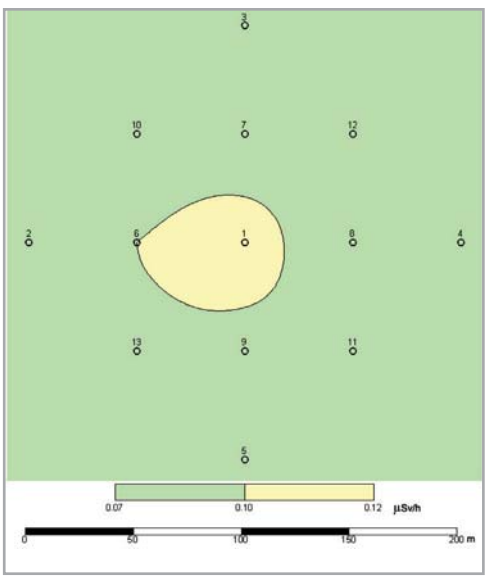
Well 131 is located in the north-western part of "Sary-Uzen" site. Currently the well area is raised in the form of a small hill within a radius of 150 m, height of 1.5-2.5 m, 40 meters from the well mouth on the south side is a failure. Well head is cut off, casing dismantled (Figure 28 a). The results of radiological survey are mapped on a diagram (Figure 28 b, c), as well as in Table 19.

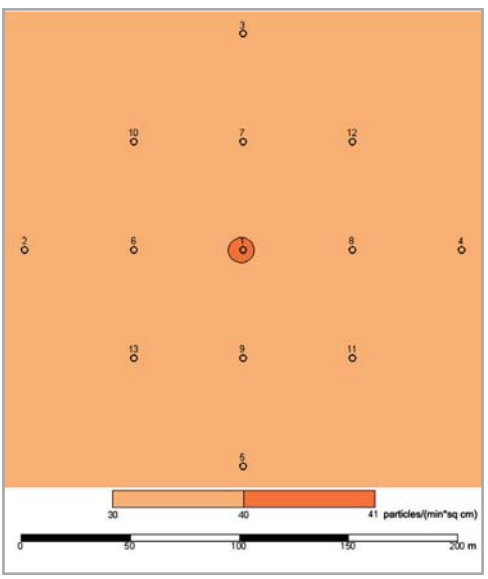
Table 19.

Results of laboratory tests of the soil from well 131

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	11.05.2006	0-5	25±2	20±2	350±6	200±140	-
1	18.08.2006	0-5	34±4	30±4	12±2	-	-
6	18.08.2006	0-5	30±5	25±5	100±5	16±4	50±10
"-" no measurement performed							

a)





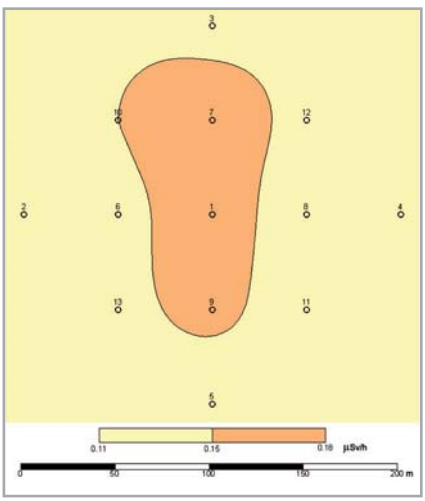
b) c)

Figure 28. Well 131: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

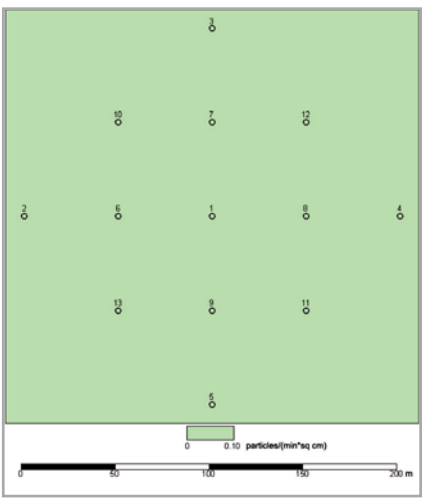
Well 132

Well 132 is located in the north-western part of "Sary-Uzen" site. Currently near the well mouth the soil surface is smooth. No post-explosion alterations seen. Well head destroyed, casing removed, an excavation with a depth of 3 m (Figure 29 a) [9]. The results of radiological survey are mapped on a diagram (Figure 29 b, c), as well as in Table 20.

a)



b)



c)

Figure 29. Well 132: a) general view on the mouth; b) EDR distribution map; c) β-particle flow density

Table 20.

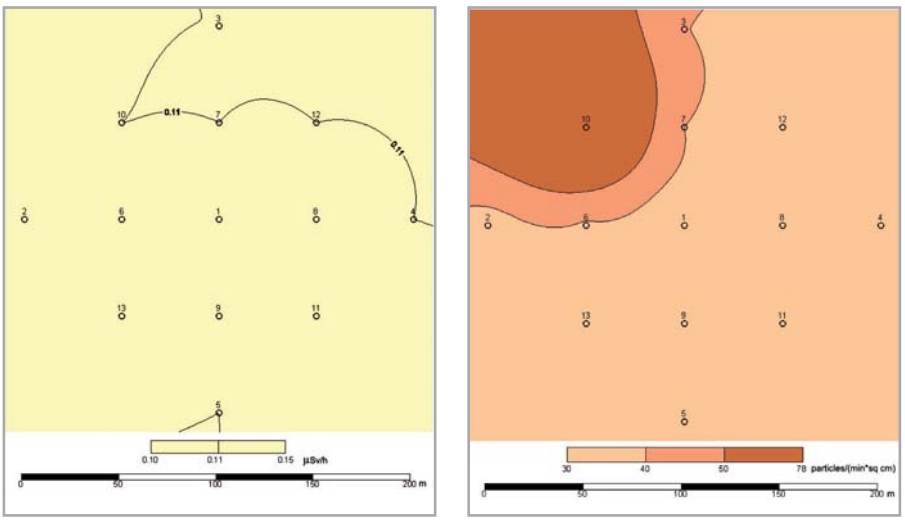
Results of laboratory tests of the soil from well 132

Point	Sampling date	Depth	Notes	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	Well head	40±10	40±10	40±6	14±4	3±2
A	18.09.2004	0-10	Maximal contamination point	50±10	45±10	40±7	40±10	20±3
1	12.04.2006	0-5	Sample taken 3m away from the pit	30±3	30±3	40±2	<100	-
1	13.09.2006	0-5	Well head	30±4	26±3	30±2	-	-
7	13.09.2006	0-5	Maximal contamination point (same as point A)	35±3	25±4	23±2	10±3	5±1
"-" no measurement performed								

Well 133

Well 133 is located in the central part of "Sary-Uzen" site. Currently there is smooth undulating terrain around the well mouth. On the west side there is a failure of about 0.5 meters deep and 80 meters long. Well casing removed, and the resulting pit has dimensions: diameter of about 4 meters, depth of 3 meters (Figure 30 a). The results of radiological survey are mapped on a diagram (Figure 30 b, c), as well as in Table 21.

a)



b) c)

Figure 30. Well 133: a) general view on the mouth;
b) EDR distribution map; c) β-particle flow density

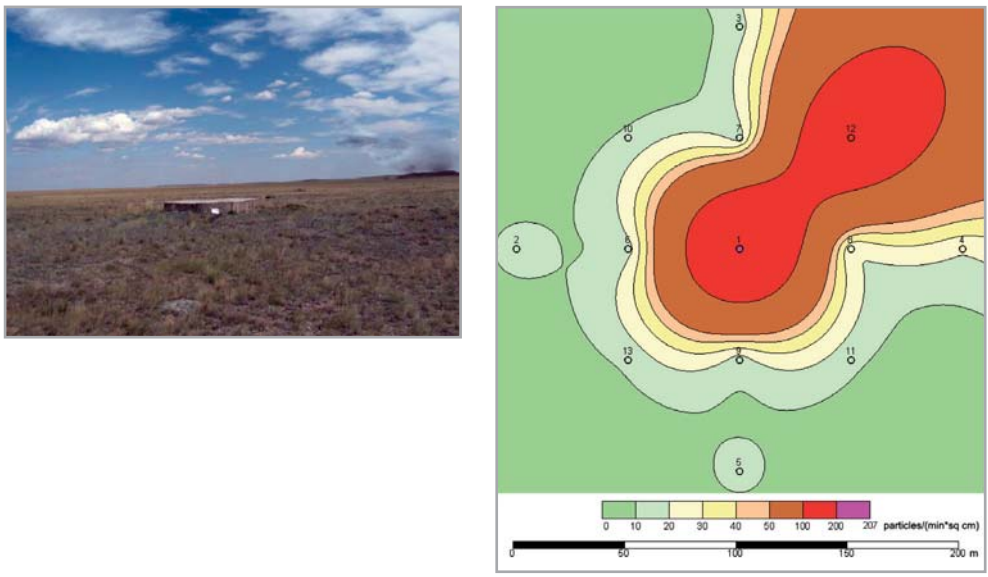
Table 21.

Results of laboratory tests of the soil from well 133

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.08.2006	0-5	40±5	30±5	300±50	220±10	15±2	2110	60±10	1900±400
10	18.08.2006	0-5	30±5	30±5	-	4±1	-	-	-	-
"-" no measurement performed										

Well 215

Well 215 is located in the north-western part of "Sary-Uzen" site. Currently near the well mouth are post-explosion alterations of the relief in the form of small swelling and failures. The well area is raised in the form of a small hill with a radius of 100 m, height of 1.5-2.0 m. The well mouth is concreted (Figure 31 a). The results of radiological survey are mapped on a diagram (Figure 31 b), as well as in Table 22.



a) b)

Figure 31. Well 215: a) general view on the mouth; b) β-particle flow density distribution map

Table 22.

Results of laboratory tests of the soil from well 215

point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{90}Sr, Bq/kg
1	18.08.2006	0-5	15±4	20±3	3 070±30	32 160±80	-	3 150±500
Max contmntn	18.08.2006	0-5	40±10	30±10	40 570±90	6 200±40	60±5	3 360±535
"-" no measurement performed								

Radiological survey of well 215 in 2008

During the areal radiological survey in the near-mouth area of well No.215 the EDR was measured at 2 299 points. Because of the large area of the radioactive trace the survey grid was 10x20 m. The range of the measured values for EDR on the ground was from <0.11 to 4.5 μSv/h.

The β-particles flux density was measured in the search mode. The values obtained at all points of the survey have not exceeded the detection limit of the tools used (10 part./(min*cm2)). The EDR and soil sampling points distribution scheme at the study area is shown in Figure 32. Of all the samples taken to determine the radionuclide composition we analyzed 18 layer-wise and 12 areal soil samples.

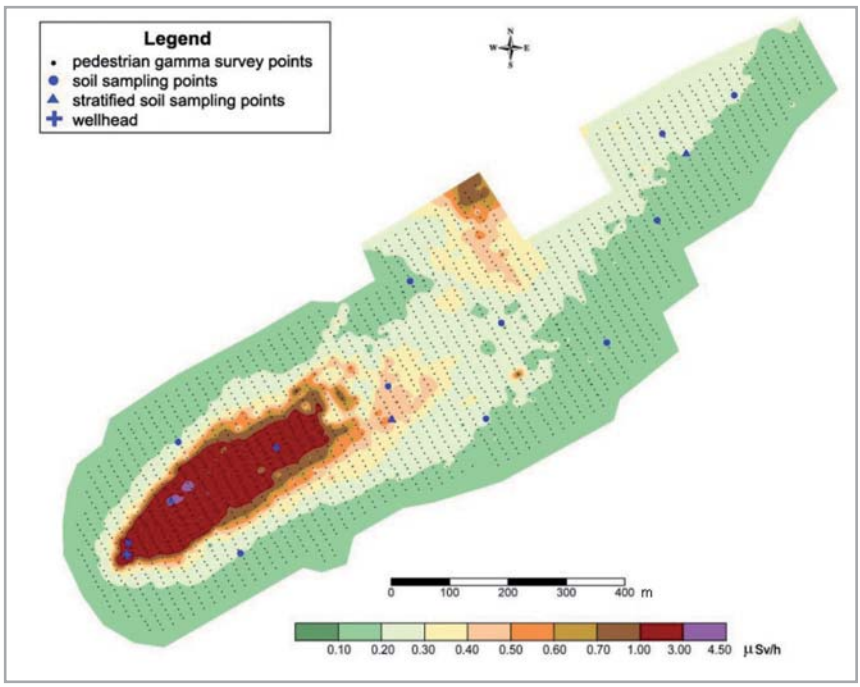


Figure 32. Distribution of EDR and soil sampling points in the surveyed area (Well No.215)

In vicinity of the well No. 215 the topsoil contamination is mainly due to the elevated concentrations of ^{241}Am, which gives a reason to believe that the content of Pu isotopes in the area may exceed the specified level of the MSSA for this radionuclide (1,000 Bq/kg) by several orders of magnitude. The most contaminated points in the area are 604, 710 and 651. At points 662, 1487, 846 concentration of ^{241}Am is several times higher than the regulatory level. For other radionuclides no exceeding over regulatory levels in the area was found, however, there is a tendency for radionuclides to increase at points 604, 710, 651 (Figure 33 a).Layer-wise distribution of radionuclides is presented in Figures 33 b, c and d. At well No.215 we collected data showing the classic distribution of radionuclides in layers – decrease in activity of ^{137}Cs and ^{241}Am with increasing depth of the layer. Upon that, the soil top layer concentrates about 74-88 % of the total amount of these radionuclides in all investigated layers. The bottom layer (40-50 cm) contains 0.1-1 % of artificial radionuclides of their total amount in all the investigated layers. Such a distribution of radionuclides is found almost throughout the STS.

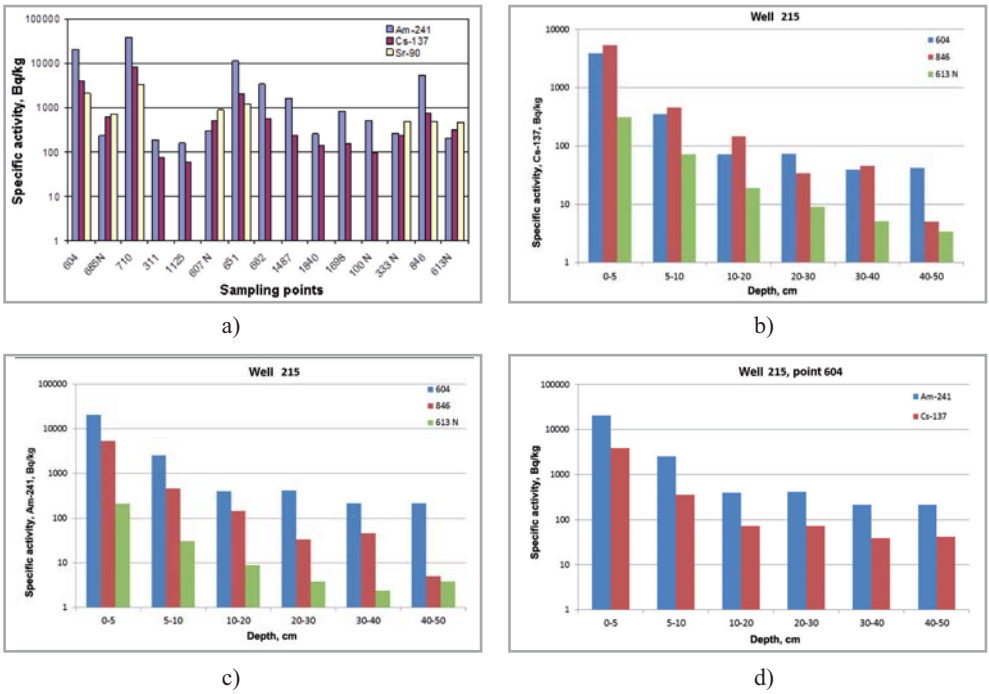


Figure 33. Well No. 215: a) distribution of artificial radionuclides in the upper soil layer; b) in-depth distribution of ^{137}Cs in the soil horizon; c) in-depth distribution of ^{241}Am in the soil horizon; d) in-depth distribution of artificial radionuclides in the soil horizon at point 604

Well 1003

14.10.1965 was the date when an underground nuclear explosion in the well 1003 was conducted at Sary-Uzen to study its peaceful applications. The explosion was accompanied by the destruction and displacement of rocks in the epicentral area and release of its radioactive products into the atmosphere in aerosol and gas phases; on the earth's surface a crater emerged. A special 1.1 kt nuclear charge was planted at a depth of 48 m (equivalent depth was 46.7 m/kt^3) [11]. Such a depth ensured a minimum release of radioactive substances into the atmosphere, and prevented the possibility of fallouts beyond USSR, the activity of which would exceed the background.

The main calculated parameters of irreversible deformation zone of the geological environment are shown in Table 23 and obtained by using the data presented in [1-4].

Table 23.

Calculated parameters of the zone with irreversible deformation of geological environment

Rock mass irreversible deformation zone	Zone radius, m
Crumple zone	10
Shatter zone	25
Intense fracturing zone	42,5
Block fracture zone (natural fracture restore)	70

The average parameters of the crater formed by the UNE are presented in Table 24.

Table 24.

Crater's average parameters

Crater diameter, m	On the primary surface	124
	On the rims	141
	On the rock piles	281
Visible crater depth, m	From the rim	29
	From the primary surface	20
Height, m	Of pile rim from the primary surface	9

Today's overview of the crater formed at UNE site at well 1003 is shown in Figure 34.

Figure 34. Overview of the crater at well 1003 (as of 03.2003)

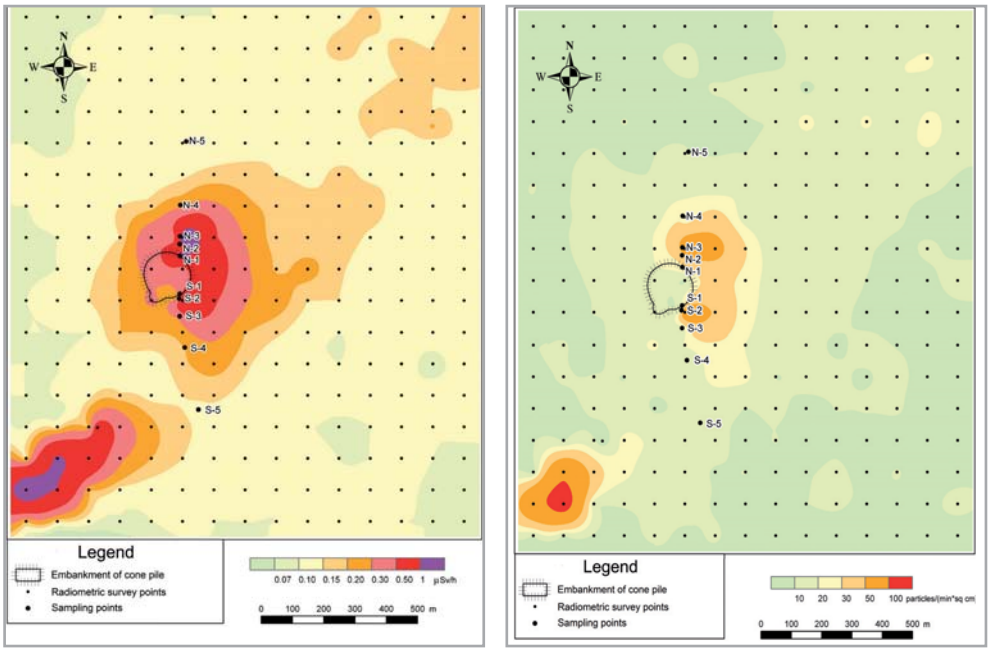
Within a year after the explosion the crater was being filled with groundwater. Total volume of water in the crater was about 500 m^3 [2].

In 1999 and 2006, as part of studies on the radioactive contamination of the territory adjacent to the emplacement well 1003, field radiometric measurements of EDR and β-particles flux density were performed and soil was sampled for laboratory analysis to determine the composition and concentration of radionuclides.

The field radiometric measurements were performed at 255 points with spacing of 100 m. The areal distribution of the radiometric parameters at the site is illustrated in Figure 35.

It is clear from the map that EDR at the site ranges between 0.007 to 1 μSv/h. The backdrop clearly identifies two areas with increased values in the south-western and central part of the site. In general, the contours of the outlined areas form a trace, which stretches in the north-east. In the central part of the site the area with an increased EDR is confined to the epicenter of well 1003. The most contaminated is the eastern part of crater heap, where the mapping marked spot with values up to 0.50 μSv/h, in the northern parts of which a maximum up to 1 μSv/h is registered. The numerical values by the density of surface contamination with β-emitting radionuclides form two less severe areas with increased values that at the test site, in general, coincide with the locations of areas with increased EDR values.

To study the areal distribution of artificial radionuclides in the study site the soil was sampled at depths of up to 5 cm and 12 cm.



a) b)

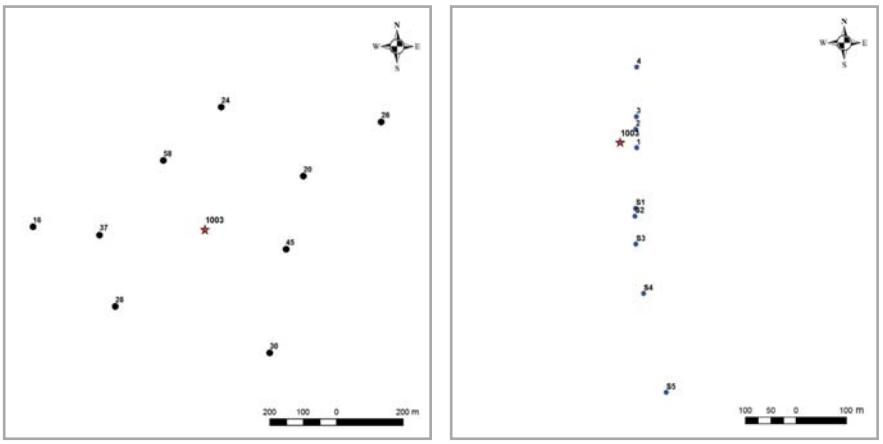
Figure 35. Well 1003: a) EDR distribution map; b) β-particle flow density distribution map

Depth of soil sampling up to 12 cm. At a depth of 12 cm soil was sampled at water wells location (Figure 36 a). The water wells are located in the area adjacent to the emplacement well 1003 at various distances – from 250 m (Well 58) to 650 m (Well 26).

Results of the laboratory tests are shown in Table 25 and Figures 37-38.

A particular attention should be paid on the features of radionuclides distribution wells 26, 30 and 45. The maximal specific activities of ^{90}Sr were registered at well 26 (1100 Bq/kg), and ^{137}Cs and ^{241}Am – at well 45 (980 and 790 Bq/kg, respectively).

Depth of soil sampling to 5 cm. Sampling points were located at different distances along the profile passing through well mouth 1003 in the northern direction (Figure 36 b).



a) b)

Figure 36. Arrangement of: a) water wells; b) soil sampling points

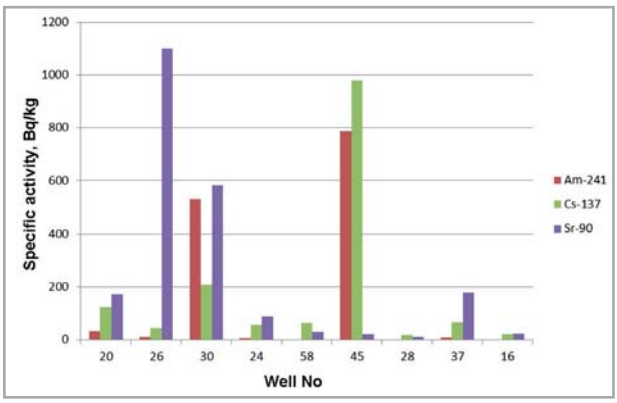


Figure 37. Distribution of artificial radionuclides in around water wells in 12 cm layer soil

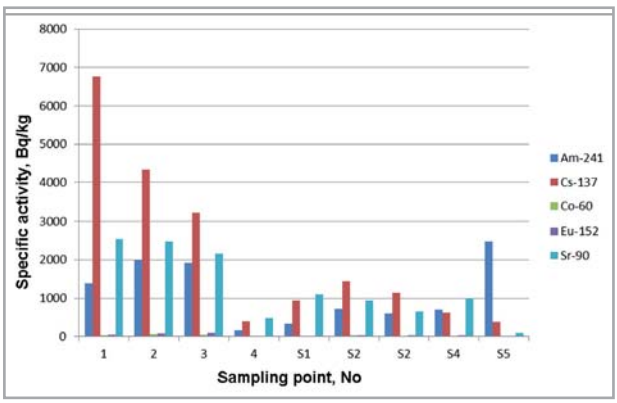


Figure 38. Distribution of artificial radionuclides in around water wells in 5 cm layer soil

Maximal concentration of ^{137}Cs – 6,760 Bq/kg was registered at sampling point 1. Further towards the point 4 there is a noticeable reduction of its specific activity. Upon that ^{90}Sr concentration at the first three points is at approximately the same level and drastically drops at point 4. The specific activity of ^{241}Am in this profile varies from 160 to 2,500 Bq/kg. The maximum was registered at S5, which has no explanation yet.

Table 25.

Results of ground samples' laboratory analysis

Point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{60}Co, Bq/kg	^{152}Eu, Bq/kg	^{154}Eu, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
Well 20	21.07.1999	0-12	21	21	34	125	-	-	-	173	410
Well 26	21.07.1999	0-12	26	33	11	44	-	-	-	1,100	128
Well 30	21.07.1999	0-12	25	28	531	209	-	-	-	582	6,790
Well 24	21.07.1999	0-12	17	35	6	58	-	-	-	87	119
Well 58	21.07.1999	0-12	22	27	-	65	-	-	-	30	24
Well 45	21.07.1999	0-12	8	32	787	979	26	29	-	20	6,980
Well 28	21.07.1999	0-12	23	30	-	18	-	-	-	11	43
Well 37	21.07.1999	0-12	22	30	8	67	-	-	-	180	154
Well 16	21.07.1999	0-12	20	23	-	20	-	-	-	24	104
epicenter	21.07.1999	0-12	19	19	160	1,860	8	-	-	850	695
pit	11.09.2002	0-10	-	-	-	-	-	-	-	47	3,100±652
1	03.11.2006	0-5	34±6	17±5	1,380±82	6,760±26	37±2	50±12	11±3	2,540±482	-
2	03.11.2006	0-5	30±7	31±9	1,990± 107	4,340±22	60±3	80±14	17±4	2,470± 468	-
2	03.11.2006	5-10	15±6	23±8	2,060±98	4,990±23	70±3	60±13	4±3	3,840± 647	-
2	03.11.2006	10-15	23±6	29±7	1,830±94	3,520±19	43±3	60±11	-	,2450± 474	-
2	03.11.2006	15-20	15±5	28±6	1,870±85	3,390±18	45±3	63±11	-	1,810± 388	-
2	03.11.2006	20-25	12±4	29±6	1,500±76	2,450±15	30±2	30±8	-	2,730± 513	-
2	03.11.2006	25-30	17±4	31±6	1,004±64	2,080±14	26±2	24±7	-	3,320± 581	-
3	03.11.2006	0-5	29±5	21±4	1,929±79	3,220±19	51±3	90±10	19±4	2,160± 435	-
4	03.11.2006	0-5	29±3	20±3	160±32	396±7	4±1	10±4	-	480± 188	-
5	03.11.2006	0-5	33±3	27±3	-	33±2	-	-	-	-	-
S1	03.11.2006	0-5	34±6	18±5	330±56	930±11	16±2	-	-	1,100± 282	-
S2	03.11.2006	0-5	36±5	22±5	720±13	1,431±16	24±3	37±8	4,5±4,3	930± 262	-
S2	03.11.2006	5-10	36±5	25±5	590±11	1,142±14	18±2	30±7	3,9±3,5	640± 212	-
S2	03.11.2006	10-15	28±4	26±4	440±9	908±12	19±2	30±7	4,5±2,7	860± 250	-
S2	03.11.2006	15-20	30±4	30±7	690±12	135±2	32±3	55±9	5,5±4,1	950± 258	-
S2	03.11.2006	20-25	30±4	22±5	920±13	1,221±14	30±3	50±8	9±4	1,180± 297	-
S2	03.11.2006	25-30	30±4	20±4	640±11	920±12	20±2	37±7	5±3,2	1,158± 296	-
S3	03.11.2006	0-5	40±4	20±3	340±44	1,000±11	10±2	33±6	10±3	297± 163	-
S4	03.11.2006	0-5	30±4	30±5	700±12	610±11	10±2	35±6	-	998± 271	-
S5	03.11.2006	0-5	26±3	25±3	2480±65	380±6	2±1	-	-	<100	-
"-" no measurement performed											

The layer-wise soil sampling was carried out at point 2 to a depth of 0 to 30 cm. Radionuclide analysis of the samples was performed to determine ^{241}Am, ^{137}Cs, ^{90}Sr, ^{60}Co and ^{152}Eu (Figure 39).

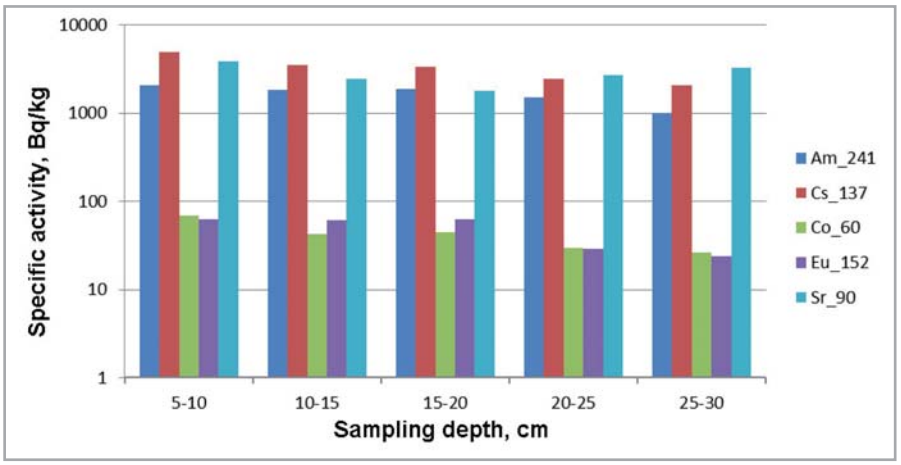


Figure 39. Depth distribution of radionuclides at sampling point 2

It is worth noting the simultaneous decrease of ^{241}Am and ^{137}Cs concentrations with depth. Concentration of ^{90}Sr also decreased gradually up to 20 cm, but then to a depth of 30 cm gradually increased to almost baseline. The maximum ^{60}Co and ^{152}Eu concentration was registered in the upper 10 cm layer.

Well 2613

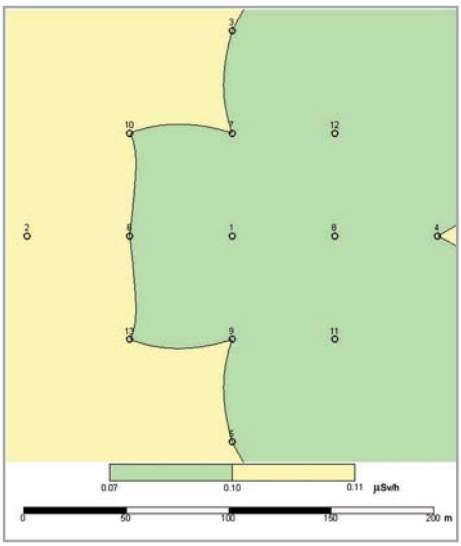
Well 2613 is located in the east near the boundary of "Sary-Uzen" site. Currently near the well mouth is a low elevation (2.5 m) to the north of the well, the surface is uneven, bumpy, on the north side one can see wavy swelling of the relief. Well casing is removed, there is an excavation with a diameter of 7.6 meters and a depth of 3 meters (Figure 40 a). The results of radiological survey is mapped on a diagram (Figure 40 b, c), and Table 26.

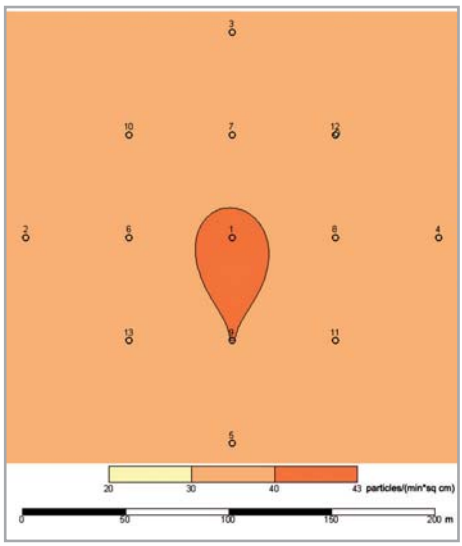
Table 26.

Results of laboratory tests of the soil from well 2613

Point	Sampling date	Depth	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
4	18.08.2006	0-5	30±4	20±3	10±2	15±4	3±1
1	18.08.2006	0-5	20±4	30±4	<0,3	-	-
"-" no measurement performed							

a)





b) c)

Figure 40. Well 2613: a) overview of the well mouth;
b) EDR distribution map; c) beta particles flux density

Well 2691

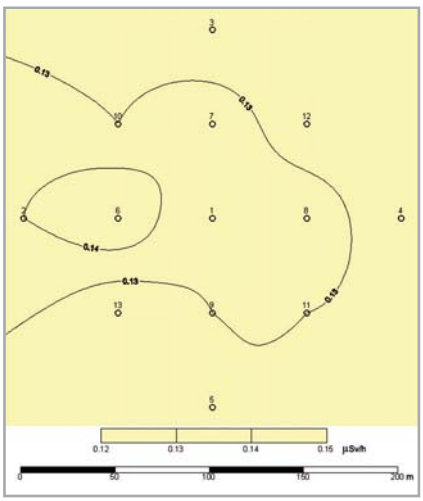
Well 2691 is located in the central part of "Sary-Uzen" site. Currently near the well mouth the post-explosion alterations on the surface are minor. Well casing is removed, there is an excavation with a diameter of 5 meters and a depth of 3 meters (Figure 41a). The results of radiological survey are mapped on a diagram (Figure 41 b, c), and Table 27.

Table 27.

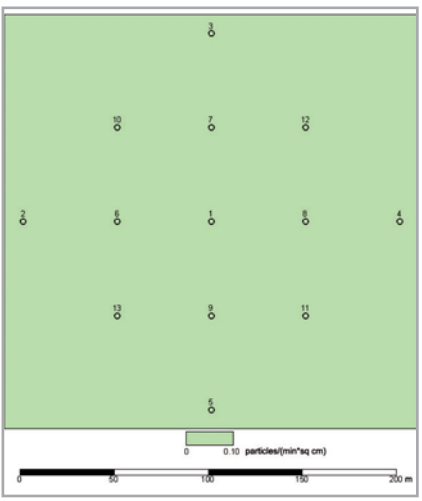
Results of laboratory tests of soil from well 2691

Point	Sampling date	Depth	Comment	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239/240}$Pu, Bq/kg
1	15.10.2004	0-10	Well head	10±2	17±2	2±1	3±2	180±41
A	15.10.2004	0-10	Maximal contamination spot	35±3	30±4	10±2	7±3	5±2
1	12.09.2006	0-5	Well head	36±3	23±2	50±2	170±30	10±2
6	12.09.2006	0-5	Maximal contamination spot (similar to point A)	30±3	25±3	22±2	-	-
"-" no measurement performed								

a)



b)



c)

Figure 41. Well 2691: a) overview of the well mouth; b) EDR distribution map; c) β-particle flux density

Well 2803

Well 2803 is located in the central part of "Sary-Uzen" site. Currently near the well mouth is a low elevation: about 2-2.5 m high, 100-120 m in radius. Around the well mouth there are swellings and failures on the Earth's surface within up to 150 meters. Well casing is dismantled (Figure 42 a). The results of radiological survey are mapped on a diagram (Figure 42 b, c), and Table 28.

Table 28.

Results of laboratory tests of soil from well 2803

Point	Sampling date	Depth	Comment	^{232}Th, Bq/kg	^{226}Ra, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	13.04.2006	0-5	Sample was taken 2-3 m away from the soil pile	30±3	35±4	32±2	-	-
1	18.08.2006	0-5	Well head	20±4	32±5	56±4	1 660±370	-
9	18.08.2006	0-5	Maximal contamination spot	10±3	23±4	76±4	3 120± 500	5±1
"-" no measurement performed								

Well X1

Well X1 is located in the eastern part of "Sary-Uzen" site. The well has a complicated engineering structure. The overview is shown in Figure 43 a, b. The results of radiological survey are mapped on a diagram (Figure 44 a, b), as well as in Table 29.

Table 29.

Results of laboratory tests of the soil from well X1

Point	Sampling date	Sampling depth, cm	Beta, μSv/h	EDR, part/(min*cm^2)	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	^{241}Am, Bq/kg	^{152}Eu, Bq/kg
1	25.08.2006	0-5	197	2	2 000±40	4 000±780	23 590±90	3 100±50
14	03.11.2006	0-5	<10	1±0,1	500±70	400±180	3 240±25	600±20
"-" no measurement performed								

Well X2

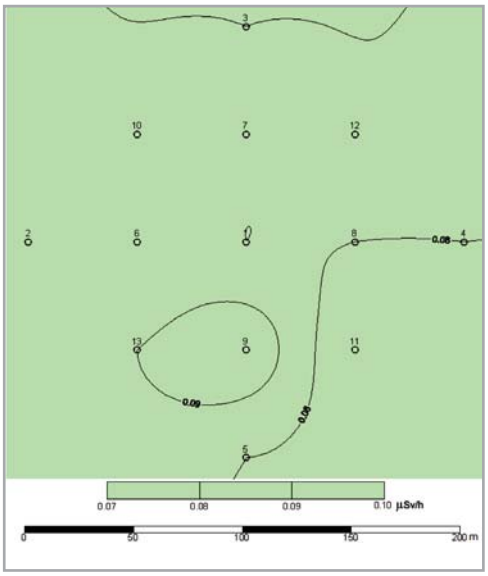
Well X2 is located in the central part of "Sary-Uzen" site. The well head is dismantled, near the mouth is an excavation with a depth of about 3 m. A general view of the well is shown in Figure 45 a. The results of radiological survey are mapped on a diagram (Figure 45 b, c), and Table 30.

Table 30.

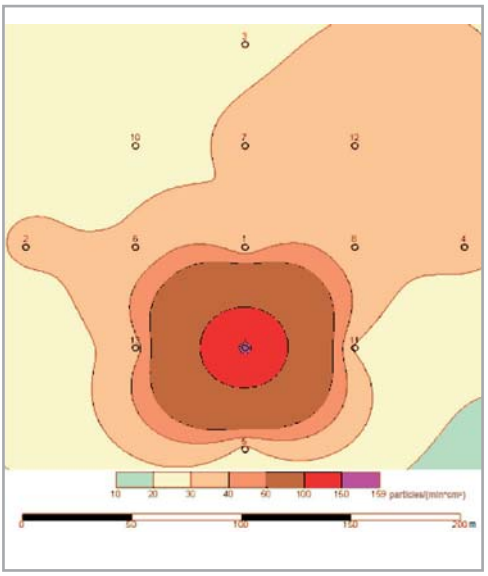
Results of laboratory tests of the soil from well X2

Point	Sampling date	Sampling depth, cm	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	4±1	3±2	90±20
A	18.09.2004	0-10	10±2	3±2	2±1
1	12.05.2006	0-5	20±2	-	-
1	25.08.2006	0-5	20±3	-	-
6	25.08.2006	0-5	100±6	50±10	50±10
"-" no measurement performed					

a)



b)

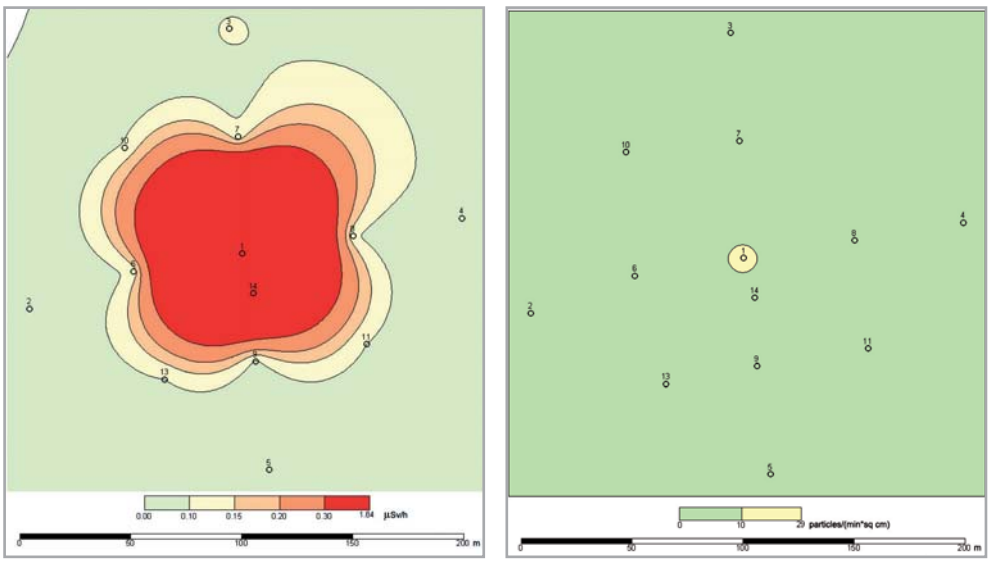


c)

Figure 42. Well 2803: a) overview of the well mouth;
b) EDR distribution map; c) β-particle flux density

a) b)

Figure 43. Well X1: a) Overview of well mouth; b) well mouth fragment



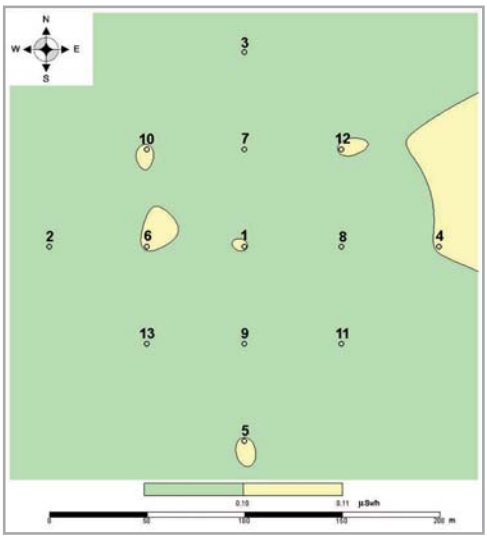
a) b)

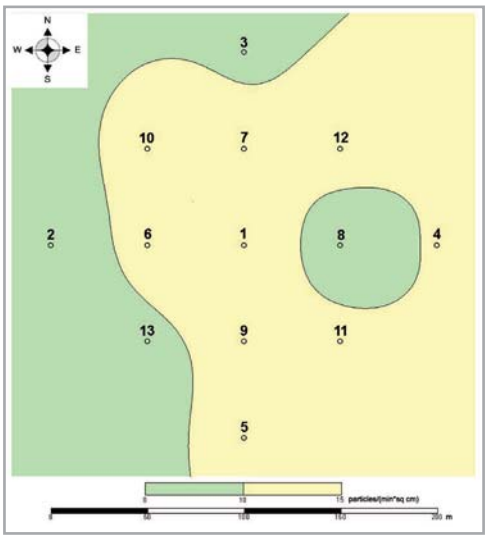
Figure 44. Distribution maps: a) EDR; b) β-particle flux density

Well X3

Well X3 is located in the eastern part of "Sary-Uzen" site. The well head is dismantled, near the mouth is an excavation with a depth of about 3 m. A general view of the well is shown in Figure 46 a, b. The results of radiological survey are mapped on a diagram (Figure 47 a, b), and Table 31.

a)





b) c)

Figure 45. Well X2: a) Overview of the well mouth. Schematic map b) EDR; c) beta particles flux density

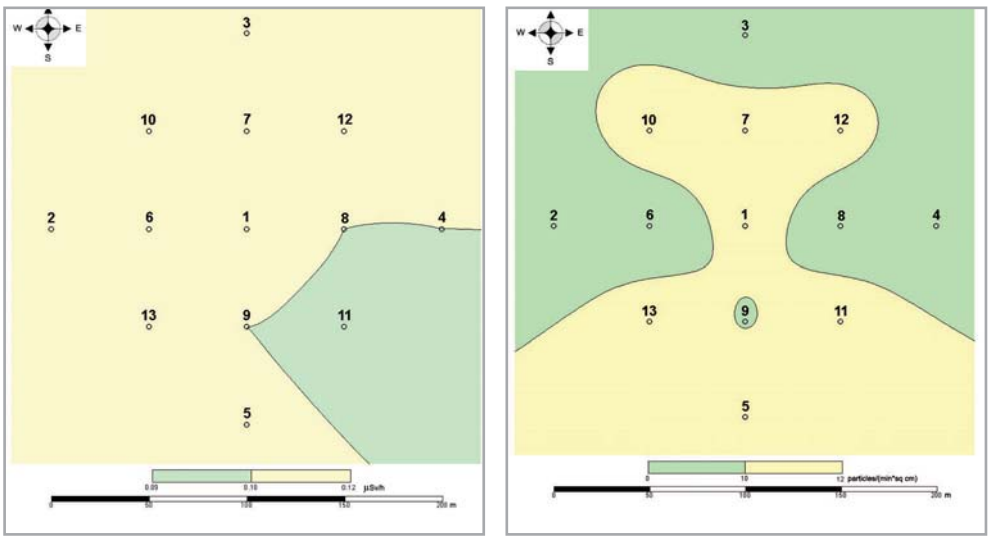
Table 31.

Results of laboratory tests of soil from well X3

Point	Sampling date	Sampling depth, cm	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	25.08.2006	0-5	100±6	10±4	600±162
13	25.08.2006	0-5	20±2	-	-

a) b)

Figure 46. Well X3: a) overview of the well mouth; b) well mouth fragment



a) b)

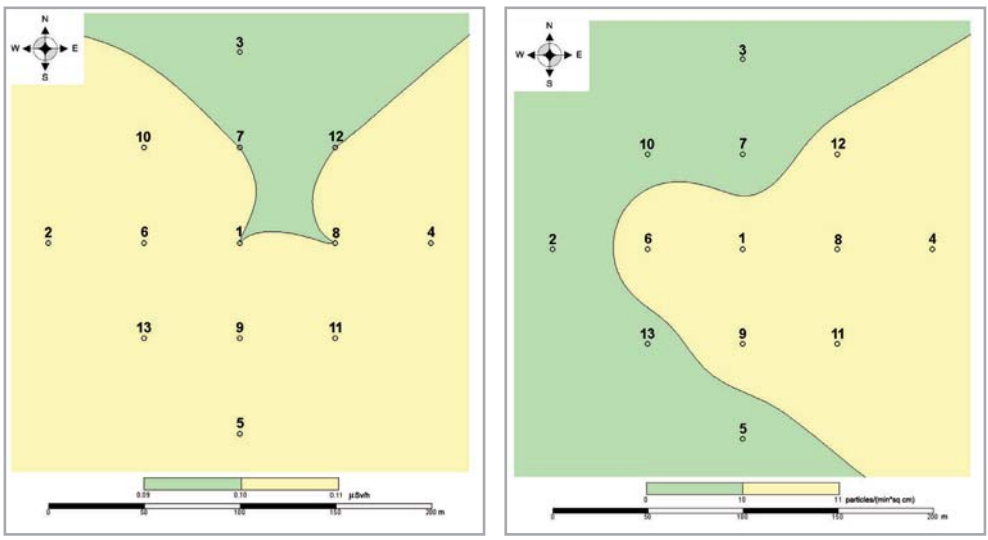
Figure 47. Schematic map: a) EDR and b) beta particles flux density at well X3

Well X4

Well X4 is located in the eastern part of "Sary-Uzen" site. The well head is dismantled, near the mouth is a deep excavation. A general view of the well is shown in Figure 48. Results of the radiological survey are mapped on a diagram (Figure 47 b, c), and Table 32.

A survey of the radiation situation was conducted in the years of 2004-2006. The test results show that EDR and beta particles flow density are at the background levels [10].

a)



b) c)

Figure 48. Well X4: a) Overview of the well mouth.
Schematic map b) EDR and c) beta particles flux density

Table 32.

Results of laboratory tests of the soil in vicinity of well X4

Point	Sampling date	Sampling depth, cm	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	18.09.2004	0-10	50±5	12±4	70±15
A	18.09.2004	0-10	20±2	10±3	-
1	25.08.2006	0-5	3±1	4±2	-
11	25.08.2006	0-5	8±1	10±4	3±1
"-" no measurement performed					

2.2. Migration of radionuclides with groundwater at "Sary-Uzen" site

2.2.1. Reconnaissance survey of water wells

Monitoring wells were drilled during the UNEs at "Sary-Uzen" site at different distances from the emplacement wells. There are no precise data on their location. Total the field survey found 247 wells of different purposes. Of these, 150 can be categorized as hydrogeological wells. These wells are unevenly cover the territory of the site and often form a cluster of wells around a nuclear device explosion site. The survey results are shown in Table 33.

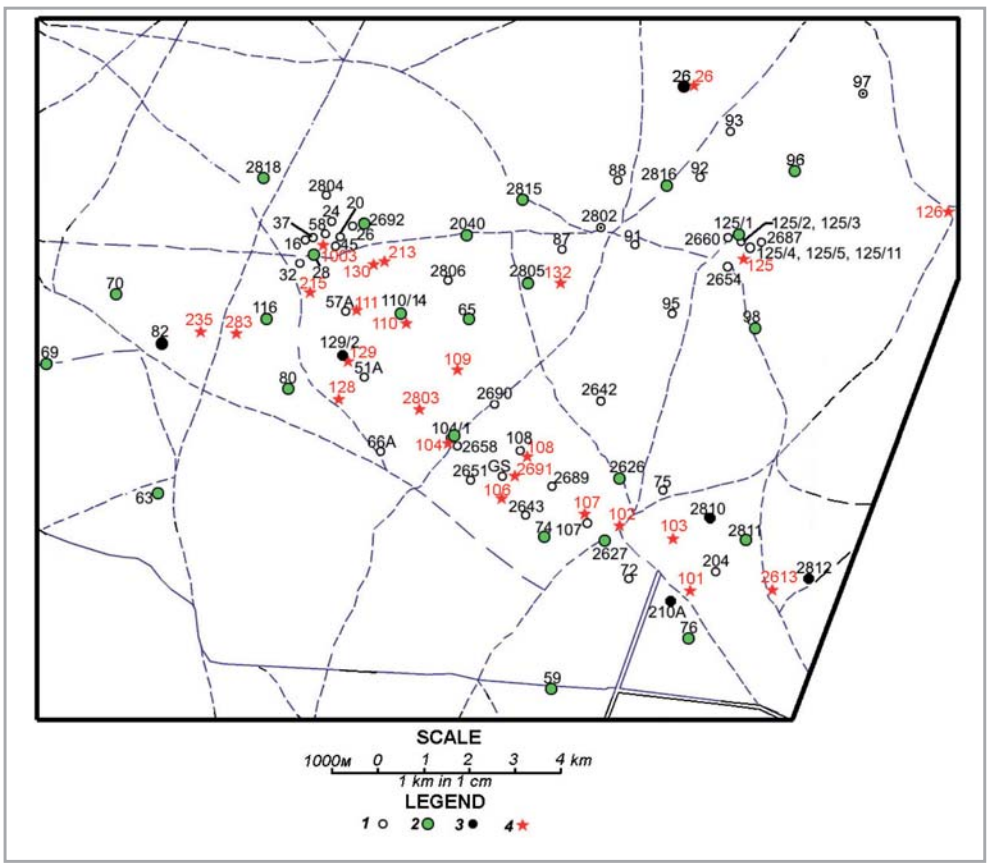
About 40 wells, most of them are equipped with metal lids, are in good condition. Currently we selected 29 wells for study the most representative hydrogeological characteristics and groundwater contamination with radionuclides. Twenty four wells turned out to be suitable for testing, which were pumped and water samples were taken for chemical and radionuclide analysis (Figure 49).

Table 33.

"Sary-Uzen" site. Data on the hydrogeological wells' clean-up

№	Well No.	Coordinates (as of WGS 84), grad, min., sec		Available depth, m	Actual depth, m	Ground water level before the clean up, m	Ground water level after the clean up, m	Notes
		Lat.N	Long.E					
1	28	49°59'21.8"	77°37'51.8"	49	49.0	20.8	19.7	-
2	26	50°01'20.8"	77°44'38.0"	5	8.0	-	-	dry
3	59	49°54'18.7"	77°42'14.6"	9.15	14.5	8.75	9.0	-
4	63	49°56'31.9"	77°35'03.3"	36.5	99.0	32	31.3	-
5	65	49°58'35.9"	77°40'42.7"	>110.0	>110.0	6.0	6.0	
6	69	49°58'05.0"	77°33'01.2"	37	40.0	6.8	7.65	-
7	70	49°58'54.0"	77°34'17.3"	88.0	88.0	21.4	22.5	-
8	74	49°56'01.6"	77°42'05.6"	17.0	32.0	16.0	15.0	-
9	76	49°54'50.7"	77°44'42.6"	85.0	75.0	8.0	8.5	-
10	80	49°57'48.0"	77°37'26.3"	19.0	71.0	17.0	17.0	-
11	82/4	49°58'18.5"	77°35'03.5"	-	-	-	-	emergency
12	96	50°00'21.5"	77°46'40.2"	17.5	21.0	11.5	12.3	-
13	98	49°58'28.8"	77°45'57.6"	49.0	10.2	10.2	11.0	-
14	104/1	49°57'07.4"	77°40'25.8"	75.0	75.0	13	-	-
15	110/14	49°58'30.0"	77°39'39.4"	94.0	75.0	9	-	-
16	116	49°58'37.5"	77°37'01.0"	15.5	82.0	11.5	12.35	-
17	125/1	49°59'35.5"	77°45'39.0"	19.0	19.1	14.7	15.3	-
1	129/2	49°58'10.4"	77°38'24.6"	-	-	-	-	emergency
19	210A	49°55'16.3"	77°44'21.4"	-	-	-	-	emergency
20	2040	49°59'35.8"	77°45'40.4"	9.9	-	-	-	-
21	2626	49°56'43.5"	77°43'26.9"	>100	>100	13.8	-	-
22	2627	49°55'59.5"	77°43'0.93"	49.0	75.0	14.2	-	-
23	2692	49°59'43.9"	77°38'46.7"	15.0	51.0	14.8	13.8	-
24	2805	49°59'02.7"	77°41'47.7"	51.2	75.0	10.7	-	-

№	Well No.	Coordinates (as of WGS 84), grad, min., sec		Available depth, m	Actual depth, m	Ground water level before the clean up, m	Ground water level after the clean up, m	Notes
		Lat.N	Long.E					
25	2810	49°56'15.8"	77°45'04.1"	5.0	6.5	-	-	dry
26	2811	49°55'59.6"	77°45'47.7"	9.7	75.0	8.0	8.0	-
27	2812	49°55'32.8"	77°46'53.1"	0.8	9.0	0.5	-	dry
28	2815	50°00'01.0"	77°41'43.1"	30.0	>150	14.4	9.8	-
29	2816	50°00'12.0"	77°44'19.8"	95.0	>150	10.8	11.6	-
30	2818	50°00'16.5"	77°36'58.0"	20.0	70.5	20.2	21.6	-

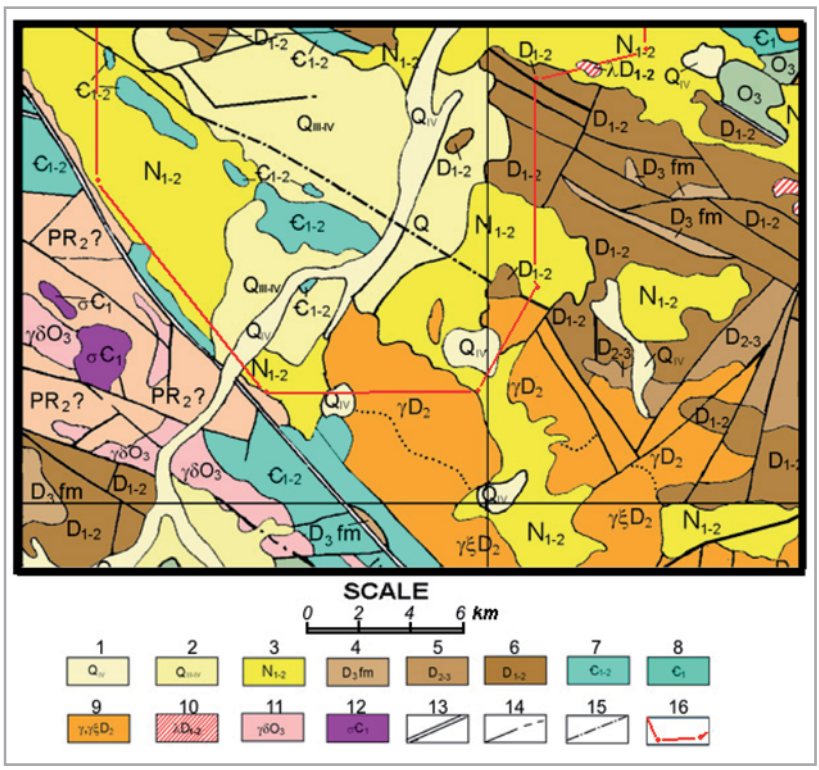


Wells: 1 – hydrogeological; 2 - hydrogeological, suitable for monitoring observations; 3 – hydrogeological, non-suitable for monitoring observations; 4 – emplacement well.

Figure 49. "Sary-Uzen" site. Arrangement of the cleaned hydrogeological wells

2.2.2. Geological and hydrogeological conditions of the artificial radionuclides migration

"Sary-Uzen" site is located within the eastern edge of Central Kazakhstan, in the intermountain valley Altybay bordered to the west by the mountain range Murzhik, to the east – mountains Maylykara and Degelen. Geomorphologically the whole area is located within the Kazakh low hills. The geological structure of the territory involves dislocated metamorphic, volcanic and sedimentary deposits of the Proterozoic, Devonian and Lower Carboniferous and horizontal lying sandy-clay loose sediments of Neogene and Quaternary Systems (Figure 50).



1 – Modern Quaternary Sediments; 2 - Upper Quaternary Modern Deposits; 3 – Neogene Clays;
4 - Upper Devonian, Famennian Stage; 5 – Sedimentary Rocks of Middle and Upper Devonian,
6 – Volcanic Rocks of Lower and Middle Devonian; 7 –Different Origin Middle Lower Cambrian Rocks;
8 – Lower Cambrian Porphyries; 9 – Middle Devonian Granites and Granosyenites;
10 – Early Middle Liparites 11 – Ordovician Granodiorite; 12 – Early Cambrian Ultrabasite;
13 – Long-Lived Faults Line; 14 – True and Alleged Tectonic Faults;
15 – tectonic contacts covered with loose sediments; 16 – "Sary-Uzen" site boundary.

Figure 50. Schematic geological map of "Sary-Uzen" site

A more detailed description of the geology and hydrogeological conditions of "Sary-Uzen" site is presented in [12].

"Sary-Uzen" site groundwater is represented by two types:

- pore waters of proalluvial and alluvial deposits;
- fracture water of the basement rocks exogenous fracturing zones.

The groundwater in the area is of mixed composition. As seen in Figure 51 – in the central and southern parts of the site the groundwater is stagnant, which causes increased mineralization (1.3-7.6 g/dm^3) of the groundwater. On this site, bordered on all sides by low hills and having an outflow point only along the dry bed of Sary-Uzen, to the north, the underground waters have chloride-sulfate sodium composition. On the periphery of the basin the groundwater is fresh, with a mineralization of, from 0.3 to 0.8 g/dm^3, chloride-sulphate-bicarbonate composition from calcium-sodium to magnesium- calcium.

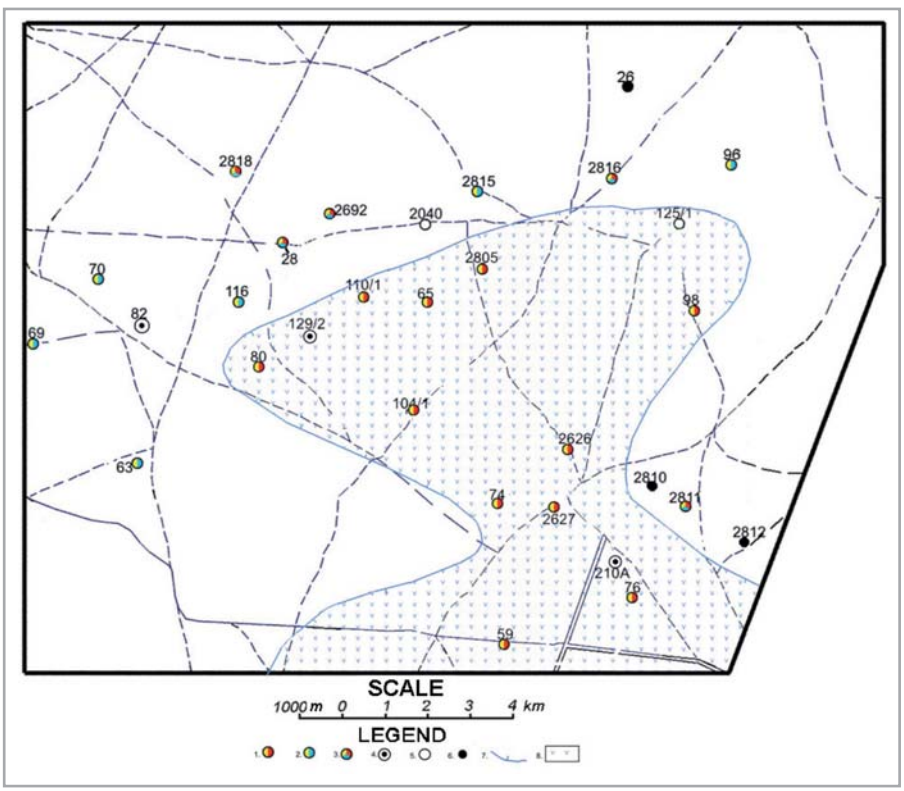
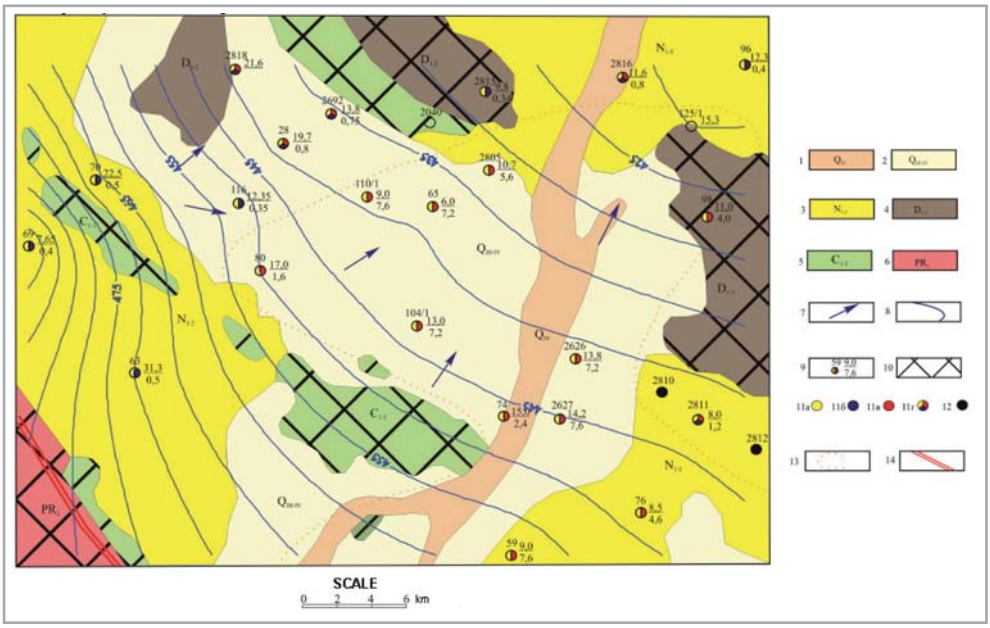


Figure 51. Schematic map of the groundwater chemistry at "Sary-Uzen" site

To analyze the structure of groundwater flow at "Sary-Uzen" site a schematic hydrogeological map was used (Figure 52). As the initial data of the map there used the absolute levels of groundwater determined during well testing and stored in an electronic database. Distribution of hydrostatic pressure values shown in Figure 52 allows us to estimate the groundwater flow direction. The regional filtration flow is directed from the recharge area to the drainage area (discharge). The direction of the flow, shown in Figure 52, provides a basis to determine the spatial position of the groundwater recharge and discharge areas. A regional drain in this case is the Irtysh River valley, and the recharge area is confined to the surface of the hilly areas in the western part of the site. The absolute benchmark changes from 500 m in the west of the site, near the regional recharge area, confined to the mountains Murzhik and Arkalyk (Major Chingiz Fault), decreasing to 200-220 m in the north-east area, in the transit zone.



1 and 2 – Quaternary Sediments Aquifers; 3 – Neogene Impermeable Clay;
4 and 5 – Paleogene basement fractured aquifer water; 6 – Proterozoic Formation;
7 –fracture water flow direction; 8 –hydroisohypses and hydroisopiezes; 9 – hydrogeological wells;
10 – recharge area of the fracture water aquifer (surface water infiltration);
11 –chemical composition of groundwater (a-sulfate anion; b-chloride anion; c-bicarbonate anion; d - mixed);
12 - water-free well; 13 - brackish water distribution area; 14 - Major Chingiz Fault.

Figure 52. Schematic hydrogeological map of "Sary-Uzen" site

The pattern of the groundwater pressure distributions shows that within the general regional background, direction of the filtration flows varies within the individual sites. This shows the heterogeneous structure of the water-bearing strata fractured space and significant heterogeneity of their filtration properties. In the central part of the territory described where emplacement wells are located, the hydroisohypses evidences a decline in the pressure gradient and the filtration rate, and, consequently, water exchange slowdown.

This is confirmed by higher mineralization of the waters (1.3 – 7.6 g/l). On this site, bordered on all sides by low hills and having an outflow point only along the dry bed of Sary-Uzen, to the north-east direction, the underground waters have chloride-sulfate sodium composition, whereas on the periphery of the site, closer to the recharge area, the groundwater is fresh, with a mineralization of, from 0.3 to 0.8 g/dm^3, chloride-sulphate-bicarbonate composition from calcium-sodium to magnesium- calcium.

2.2.3. Levels of groundwater radioactive contamination at "Sary-Uzen" site and adjacent areas

2.2.3.1. Groundwater conditions at "Sary-Uzen" site

In 2005, at "Sary-Uzen" site twenty water wells were tested (Figure 53), in 2010 – 10 water wells (Table 34).

The laboratory tests showed that the radionuclides concentration in groundwater, widespread within the site area, reaches the following quantities: ^{137}Cs to 3 mBq/l, ^{90}Sr up to 10 mBq/l, ^{3}H up to 500 kBq/l. The presented data demonstrate that the main radioactive contaminant of the groundwater at the site is ^{3}H. Upon that, concentrations of ^{137}Cs and ^{90}Sr in the water pose no radiation danger and do not exceed the regulatory limits for drinking water.

Table 34..

Comparative data on tritium specific activity (kBq/l) in water samples taken from water wells at "Sary-Uzen" site

Well No.	before 2010	2010	Well No.	before 2010	2010
28	<0.21	0.03	**116**	<0.007	-
59	0.01	<0.008	**125**	482	-
63	<0.007	-	**189B**	0.017	-
65	0.04	0.3	**2626**	0.49	0.2
69	<0.007	-	**2627**	0.012	-
70	<0.007	-	**2692**	0.012	-
74	<0.007	-	**2805**	0.018	-
76	<0.007	<0.008	**2805/1**	-	5
80	<0.006	-	**2811**	3.2	-
96	0.03	0.03	**2815**	0.8	25
98	0.009	-	**2816**	4.4	4
104/1	46.82	-	**2818**	0.01	-
110/14	65.8	30			
"-" no measurement performed					

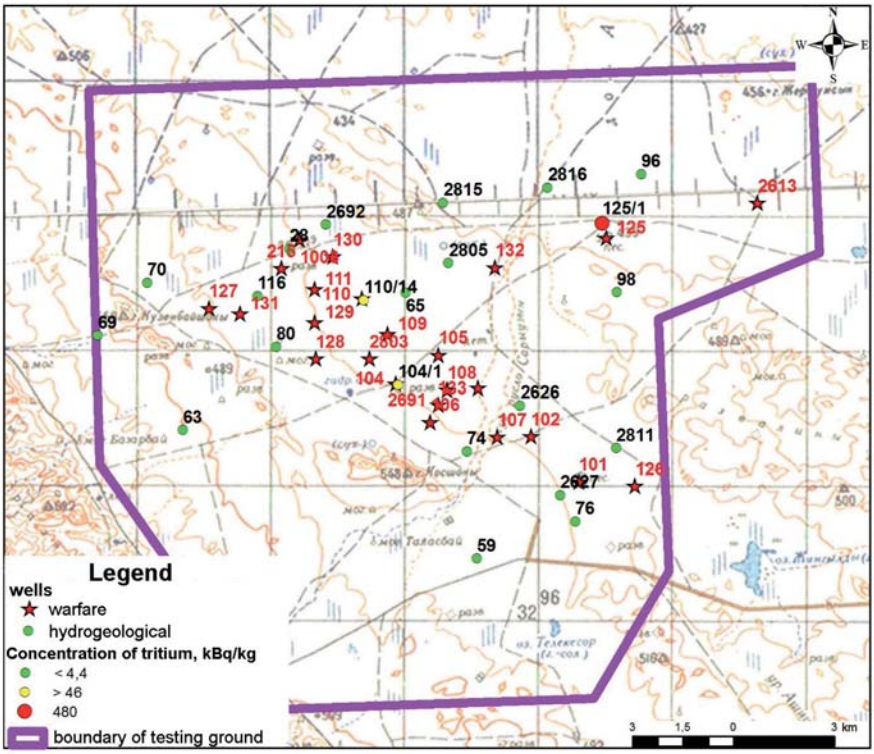


Figure 53. "Sary-Uzen" site. Arrangement of the water (hydrogeological) wells

Analysis of the data showed that the dynamics of ^{3}H concentration at the site is of ambiguous of character. Areal distribution features of tritium in groundwater are largely dependent on the groundwater flow direction. This is clearly shown by the tritium concentration displayed in Figure 53. An analysis of the data can identify a number of wells with extremely low tritium concentrations to the minimal detectable activity level (MDA) of the equipment used. These are water wells (No. 59, 63, 69, 70, 74, 76) which are arranged outside the contaminated waters migration front. Data on these wells show that within the area, despite a complex geological structure, there is no migration of the artificial radionuclides with groundwater in the opposite direction of the regional groundwater flow.

Maximal concentration of tritium (482 kBq/l) was registered in well 125/1 located 460 m to the North of emplacement well 125. For comparison, well 104/1 is located just 80 meters away from emplacement well 104, but the tritium concentration is for an order of magnitude smaller than that in well 125/1. This difference can be explained by the following factors. First, well 125/1 is located northerly (within the main direction of groundwater flow) from the contamination source, which is emplacement well 125. Also confined groundwater is widespread within well 125, which contributes to greater leaching of radionuclides from the UNE central zones into groundwater aquifer. In contrast to 125/1, well 104/1 is located

easterly of emplacement well 104 and stagnant ground water is widespread within the area where well 104/1 is located.

It should be noted that moving away from the emplacement wells, in the first kilometers the tritium concentration in water is significantly reduced. This is evident in well 96 located 2 km to the north-east of emplacement well 125, as well as in a number of other wells.

2.2.3.2. Investigation of the groundwater conditions outside the northern boundary of "Sary-Uzen" site

To study possible migration of contaminated groundwater beyond "Sary-Uzen" site towards Irtysh River currently we are using data from the testing of water wells located at "Novaya" site. This site is located on the northern boundary of "Sary-Uzen" site, i.e. on the possible pathways of underground water flow to the north. At the time of the nuclear tests at "Novaya" site preliminary works were done for UNE in the wells. To this end, 19 water wells were arranged on the site.

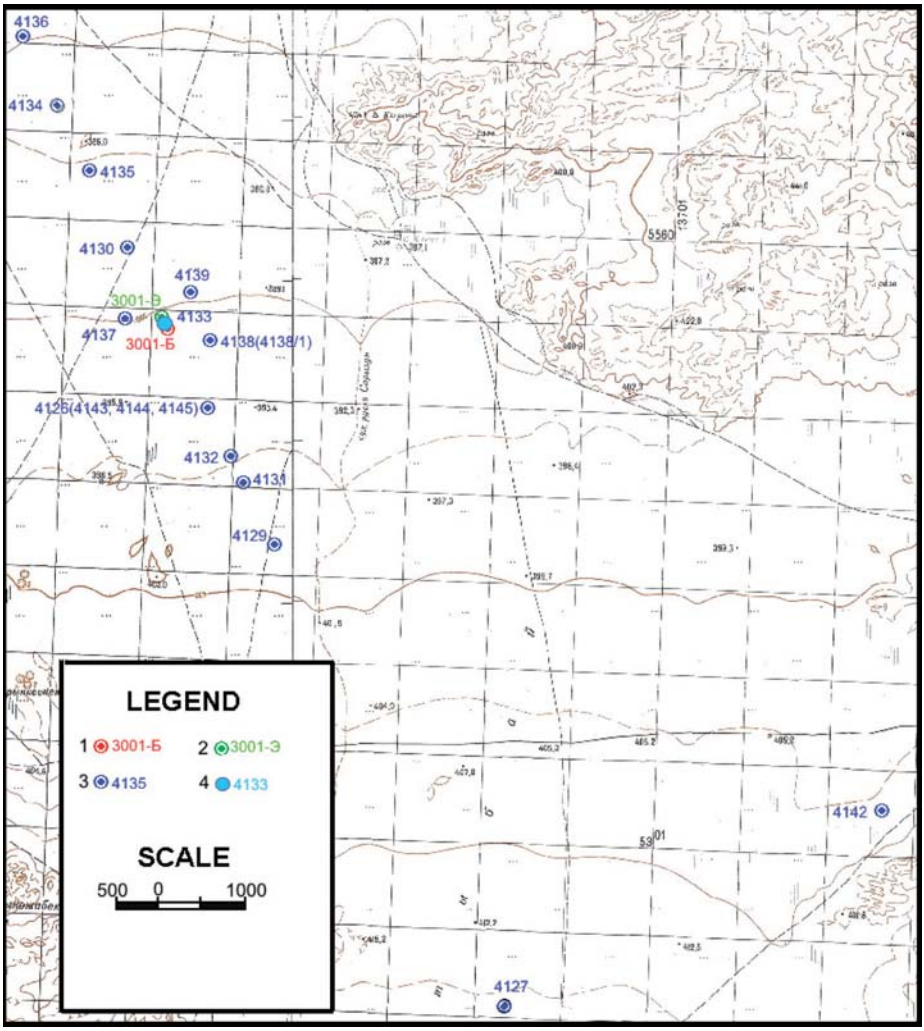
The water wells were examined and then followed by assaying the groundwater. Seventeen water wells, drilled to the horizon of fracture and pore waters, were found. The results of post-processing and field survey are summarized in Table 35 and Figure 54.

Well 4133 was cleaned up, where groundwater was pumped out and sampled for laboratory analysis for artificial radionuclides and reduced chemical analysis.

Table 35

"Novaya" site. Surveyed water wells characteristics

No.	Well No.	Actual Elevation, m	Well depth, m	Available depth, m	Underground water table	Pressure head, m	North latitude	Eastern longitud	Note
1	4126	393.5	267.6	-	7.7	32.3	50º 07' 12.8"	77° 44' 08.4"	Concrete plug
2	4127	415.6	81.4	-	9.4	-	50° 03' 30.1"	77° 47' 00.3"	Concrete plug
3	4129	398.2	133.9	11.2	10.20	12.3	50° 06' 22.0"	77° 44' 47.2"	Metal covering
4	4130	388.2	300.0	-	5.5	-	50° 08' 12.7"	77° 43' 22.1"	Concrete plug
5	4131	395.9	100.2	-	9.65	26.3	50º 06' 45.1"	77° 44' 29.4"	Concrete plug
6	4132	395.0	99.2	9.1	8.8	22.7	50° 06' 54.9"	77° 44' 22.0"	Metal covering
7	4133	390.6	90.0	-	6.0	32.5	50° 07' 44.5"	77° 43' 43.6"	Concrete plug
8	4134	383.3	300.0	-	4.3	-	50° 09' 05.3"	77° 42' 41.6"	Concrete plug
9	4135	385.6	105.0	-	2.85	31.1	50° 08' 41.0"	77° 43' 00.2"	Concrete plug
10	4136	380.1	102.6	4.3	4.15	-	50° 09' 31.1"	77° 42' 21.3"	Geo equipment left in the well
11	4137	390.1	300.0	7.05	7.0	-	50° 07' 46.1"	77° 43' 20.6"	Well open
12	4138	391.4	153.7	-	6.25	38.8	50° 07' 37.9"	77° 44' 09.7"	Concrete plug
13	4139	390.0	93.0	-	5.7	21.3	50° 07' 56.0"	77° 43' 58.6"	Well is full of cores and stones
14	4142	406.6	69.0	7.85	7.6	-	50° 04' 42.5"	77° 50' 38.9"	Metal covering
15	4143	393.5	24.0	-	8.1	-	50º 07' 12.8"	77° 44' 08.3"	Concrete plug
16	4144	393.5	16.0	8.2	8.0	-	50º 07' 12.9"	77° 44' 08.2"	Open
17	4145	393.5	17.0	-	8.0	-	50º 07' 12.9"	77° 44' 08.2"	Concrete plug



Wells: 1 – emplacement; 2 – structure well; 3 – water well; 4 – observation well, cleaned in 2006.

Figure 54. Arrangement of water wells at "Novaya" site

To study the migration of radionuclides at "Novaya" site, 4 wells were tested in 2006. Analyzes of the samples showed that the concentration of ^{3}H in groundwater at the site ranges from <7 to 20 Bq/l, which is significantly below the intervention level by the content of individual radionuclides in drinking water [10].

In 2010, to assess the possible redirection of the contaminated water flow from "Sary-Uzen" site in a northerly direction, three previously drilled wells were tested at "Novaya" site (Figure 54). According to the laboratory analyzes no artificial radionuclides in groundwater

at the sites were found. Thus, the water well testing did not find any movement of artificial radionuclide contaminated groundwater flow from "Sary-Uzen" site to the north.

CONCLUSIONS

1. Radioactive contamination of the soil at "Sary-Uzen" site

Thus, the data obtained from the medium-scaled survey gives a reason to believe that the contamination of soil on the surface area at "Sary-Uzen" site was the result of the long-range fallout from the above-ground nuclear explosion performed on 24.09.51., as well as from the short-range fallouts caused by releases of radioactive gases and aerosols during the UNE in the emplacement wells at "Sary-Uzen" site. The radioactive contamination spots within the emplacement wells have a local character. No effect of model experiments on the radioactive contamination of the soil cover at "Sary-Uzen" site was found.

The study of the radionuclides in-depth distribution during the areal surveys showed that the specific activity of radionuclides goes down with the depth. Upon that, although ^{90}Sr specific activity decreases with depth, there is no sharp decline in its activity. It is distributed in the soil profile more uniformly, unlike ^{137}Cs and $^{239+240}Pu$. The considerable amount of ^{90}Sr in the lower layer (10-15 cm) confirms its high migration capacity, and also implies the presence of this radionuclide in the deeper layers of the soil profile. The distribution pattern of $^{239+240}Pu$ is identical to the distribution of ^{137}Cs.

The radioactive contamination of soil in the near-mouth areas differs by both specific activity levels, radionuclide composition, and area of distribution. By radionuclides concentration the topsoil around wells 104, 127, 133, X1 101, 111, 125, 215, 1003 can be categorized as radioactive waste, at wells 102, 106, 108, 130, 131, 2803, X2, X3, X4 – as limited use materials. In the near-mouth areas of other wells the radionuclide content does not exceed acceptable levels, mainly at the level of the background of global fallout.

2. Conditions of the underground waters at "Sary-Uzen" site

The regional filtration flow has north-east direction. The recharge area is confined to the elevated areas of the surface in the western part of the site. The regional drain is the Irtysh River Valley.

The concentration of artificial radionuclides in groundwater, widespread within the site area, reaches the following quantities: ^{137}Cs up to 3 mBq/l, ^{90}Sr up to 10 mBq/l, ^{3}H up to 500 kBq/l. The presented data suggest that the main radioactive contaminant of the groundwater is ^{3}H. Although, concentrations of ^{137}Cs and ^{90}Sr in water do not exceed the permissible values for drinking water.

Testing of water wells in 2005 and 2010 showed a trend of gradual decline of ^{3}H concentration in the groundwater.

The areal distribution of tritium in groundwater depends on the direction of groundwater flow. In the first kilometers away from the emplacement wells the concentration of tritium in water is significantly reduced.

According to the results of the water well testing in 2010 at "Novaya" site no movement (redirection) of artificial radionuclide contaminated groundwater flow from "Sary-Uzen" site to the north is currently observed.

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ССП «САРЫ-ӨЗЕН» СЫНАҚ АЛАҢЫНДАҒЫ ҚОРШАҒАН ОРТАНЫҢ ҚАЗІРГІ РАДИОЭКОЛОГИЯЛЫҚ АХУАЛЫ

[1]Субботин С.Б., [1]Стрильчук Ю.Г., [1]Новикова Е.А., [1]Романенко В.В., [2]Пестов Е.Ю.,[2]Бахтин Л.В.

[1]ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан
[2]ҚР ҰЯО Геофизикалық зерттеулер институты, Курчатов, Қазақстан

Мақалада, «Сары-Өзен» сынақ алаңындағы радиациялық жағдайдың қалыптасу механизмдері мен факторлары қарастырылды. «Әскери» ұңғымалардың сағалық алаңдарының шегіндегі топырақтың радиоактивті ластану деңгейін зерттеу нәтижелері келтірілді. Аталған сынақ алаңындағы жерасты суларының қазіргі радиоэкологиялық ахуалы, сонымен қатар «Сары-Өзен» алаңының шегінен тыс жерлерге ластанған жерасты суларының мүмкін деген таралу жолдары қарастырылды.

Кілт сөздер: «Сары-Өзен» алаңы, аузы, «әскери» ұңғымалар, топырақтың радиоактивті ластануы, жерасты суларының жылыстауы.

СОВРЕМЕННОЕ РАДИОЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ ОКРУЖАЮЩЕЙ СРЕДЫ НА ИСПЫТАТЕЛЬНОЙ ПЛОЩАДКЕ СИП «САРЫ-УЗЕНЬ»

[1]Субботин С.Б., [1]Стрильчук Ю.Г., [1]Новикова Е.А., [1]Романенко В.В., [2]Пестов Е.Ю., [2]Бахтин Л.В.

[1]Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан
[2]Институт геофизических исследований НЯЦ РК, Курчатов, Казахстан

В статье рассмотрены факторы и механизмы формирования радиационной обстановки на площадке «Сары-Узень». Представлены результаты исследований уровней радиоактивного загрязнения грунтов в пределах приустьевых площадок «боевых» скважин. Рассмотрено современное радиоэкологическое состояние подземных вод на данной испытательной площадке, а также возможные пути распространения загрязненных подземных вод за пределы площадки «Сары-Узень».

Ключевые слова: площадка «Сары-Узень», оголовок, «боевые» скважины, радиоактивное загрязнение грунтов, миграция подземных вод.

УДК 614.876:621.039.7:504.064:539.16

STUDY OF THE CHARACTER AND RADIOACTIVE CONTAMINATION LEVELS AT THE RADIOACTIVE WARFARE TEST GROUNDS

Ossintsev A.Yu., Salmenbaev S.E.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

The paper describes the investigations for determination of artificial radionuclide concentrations in the soil cover of the Radioactive Warfare Agents (WRA) test ground 4"A". The investigations found that the radioactive contamination is caused by the presence of such radionuclides as ^{90}Sr, ^{241}Am, $^{239+240}$Pu, ^{137}Cs, ^{152,154,155}Eu and ^{60}Co, the main one of which is ^{90}Sr. The study of the radionuclide vertical distribution showed that the major activity of ^{137}Cs, ^{241}Am and ^{152,154,155}Eu is in the top 20 cm soil layer. Furthermore, we found areas with abnormal in-depth distribution of radionuclides on the soil profile, where maximal concentrations of the radionuclides investigated were in the 10-20 cm layer. Studies of the isotopic ratio showed that it is impossible to interrelate the contaminated areas by possible contamination source based on the obtained ratios and spatial location.

Keywords: test ground, radionuclide composition, radioactive contamination, radioactive wastes, radionuclides vertical distribution, total indicator of radioactive contamination.

INTODUCTION

The test ground 4"A" is one of the two test grounds located in northwestern part of the Semipalatinsk Test Site, (STS) where radioactive warfare agents were tested (Figure1).

The test grounds were used to study the damaging action of highly active liquid and powder radioactive substances produced from wastes of radiochemical production in order to develop mass destruction weapons.

The aim of the previous examinations of WRA test grounds 4 and 4"A" [1, 2, 3, 4] was to discover and to contour the areas of radioactive contamination, and therefore they could not give a detailed picture of the radiation situation. Thus, the aerial gamma-spectrometric survey in the early 1990s enabled scientists to make a conclusion that there were no areas with increased density of ^{137}Cs contamination in soil, and that as a result of decay of radionuclides from the radioactive warfare agents the density of radioactive contamination was close to the background values [1].

During examination of the territory of the test ground specialists of the IRSE NNC RK discovered the places of WRA tests [2]. As a result of field works they discovered fragments of metal fabrics used in tests and spots of local radioactive contamination. In soil samples taken during field works from the crater, presumably for EDR after the explosion of an WRA projectile, the activity of some artificial radionuclides was determined. The following values were obtained: the concentration of cesium-137 was 3,470 Bq/kg, cobalt-60 – 370 Bq/kg, ameritium-241 – 9,800 Bq/kg, europium-152 – 370 Bq/kg and europium-155 – 4,100 Bq/kg [2].

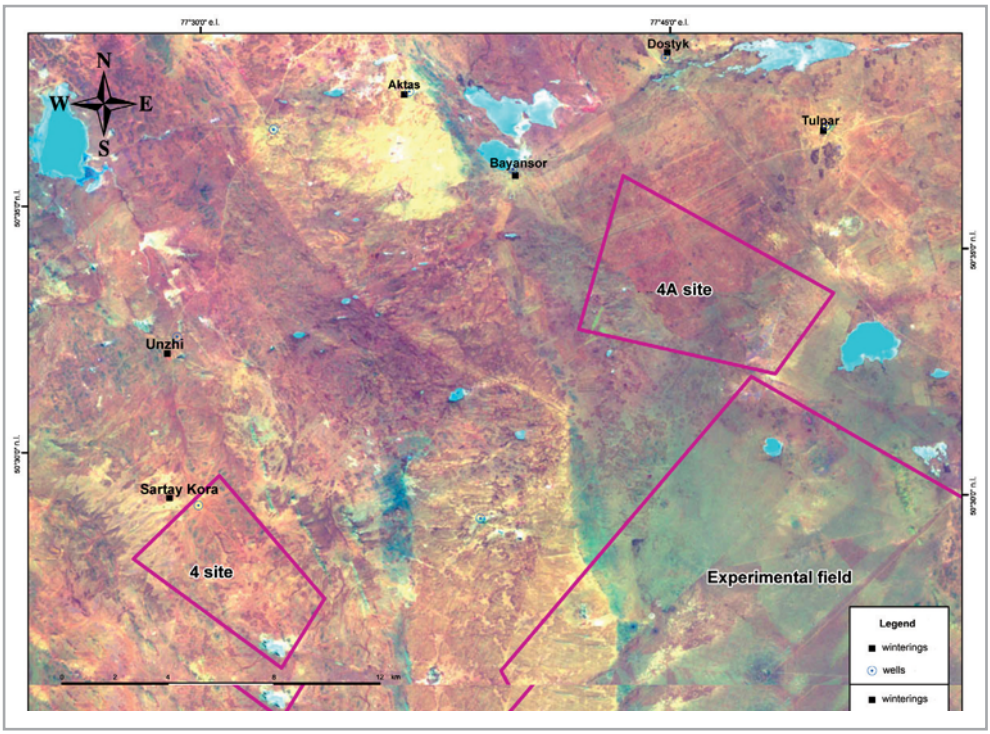

Figure 1. WRA test grounds 4 and 4 "A"

In 2005 beta- and gamma-survey of the area of the test ground 4"A" was made [3]. During that investigation the radioactive composition of radioactively contaminated spots was not studied.

The aim of the present work is to determine the character and levels of radioactive contamination of the area of the test ground 4 "A".

To fulfill the task of the research it was necessary to solve the following problems:

- To obtain information on the levels of concentration of artificial radionuclides in the soil cover of the test ground;
- To study specific features of radionuclide distribution in depth along the soil profile and based on these results to determine possibility of soil reclamation by removal of contaminated soil;
- To characterize radioactively contaminated spots in terms of possible sources of radionuclides.

1. EXPERIMENTAL PART

To fulfill the above-stated tasks, layer-by-layer and point soil samples were taken in 25 ground spots detected as a result of previous field works and classified as radioactively-hazardous objects [4]. The samples were taken in the points with maximal values of radiation parameters (EDR, beta-flux density) (Table 1).

Table 1.

Values of radiation parameters measured in soil sampling points

Spot No.	Radiation parameters		Section No.	Radiation parameters	
	EDR (h=1m), μSv/h	β-flux density, part/(min·cm²)		EDR (h=1m), μSv/h	β-flux density, part/(min·cm²)
1	17	>6,000	14	6	4,000
2	59	>6,000	15	26	>6,000
3	44	>6,000	16	56	>6,000
4	26	>6,000	17	14	>6,000
5	13	>6,000	18	104	>6,000
6	0.9	1,700	19	10	>6,000
7	1.5	1,200	20	46	>6,000
8	31	>6,000	21	35	>6,000
9	1.3	1,800	22	7	3,000
10	14	>6,000	23	4,7	2,000
11	31	>6,000	24	10	5,000
12	41	>6,000	25	38	>6,000
13	108	>6,000			

Location of the studied spots on the territory of the test ground, sampling places and places of shafts drilling are shown in Figure 2.

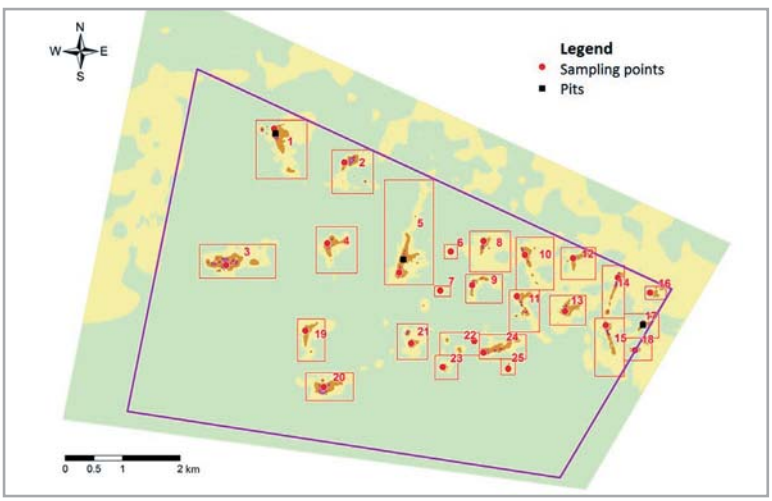

Figure 2. Location of radioactively contaminated spots on the test ground 4 "A"

1.1. Sampling

Point samples were taken using special sampling instruments to a depth of 10cm from the area of 100 cm^2. Location of the sampling points was determined by the geodesic coordinate system where B is a geodesic latitude and L is a geodesic longitude (in degrees, minutes and seconds). The precision in determination of coordinates by the GPS-receiver was 3-5 meters with probability of 95%.

Layer-by-layer sampling from prepared shafts of a depth of 70cm was made in spots No.1, No.5 and No.17, in the point with maximal values of EDR and beta-density. The thickness of layers for sampling was 5 and 10cm (layers: 0-5, 5-10, 10-15, 15-20, 20-30, 30-40, 40-50, 50-60 cm).

1.2. Laboratory analysis

The soil samples were analysed in the IRSE laboratory of radiochemical analysis according to standards and methodological documents. Preparation of samples for the laboratory analyses included such operations as drying, sieving, separation of admixtures, grinding and quartering.

To measure activities of gamma-radiating objects we used gamma-spectrometer GX 2020 with Ge-detector with 20% relative registration efficiency according to the method of measurements described in [5]. The ^{90}Sr concentration in soil samples was determined by beta-spectrometer "Progress" with NaI detector [6]. The values of $^{239+240}Pu$ activities were determined by radiochemical analysis [7]. The obtained values of specific activities were further used in calculations of isotopic ratios of radionuclides (Table 4).

2. RESULTS

2.1. Estimation of radionuclide composition of radioactively contaminated spots

Values of specific activity of radionuclides from point soil samples (0-10cm) are presented in Table 2.

The above data show that the main contaminator of the soil cover is radionuclide ^{90}Sr, however, a considerable contribution to the radiation safety is also made by plutonium isotopes. The total indicator of radioactive contamination in all studied spots is several orders of magnitude higher than 1, hence, the soil cover of the studied spots (0-10 cm) refers, according to normative documents [8], to solid radioactive wastes.

In further reclamation works it is reasonable to start works on removal of contaminated soil from the spots with maximal contamination $\sum C_i/MVA_i$ (spot No.18, spot No.13, etc.).

Table 2.

Specific activity of ^{241}Am, ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in soil samples taken from the studied areas

Sampling point	Specific activity								$\sum C_i/MSA_i^*$
	MBq/kg	kBq/kg						Bq/kg	
	^{90}Sr	^{241}Am	^{137}Cs	$^{239+240}$Pu	^{152}Eu	^{154}Eu	^{155}Eu	^{60}Co	
sect. 1	4.7±0.5	0.5±0.02	1.1±0.01	8.4±0.4	0.08±0.01	0.24±0.01	0.1±0.02	10±2	**480**
sect. 2	13±1	1.6±0.3	1.4±0.3	12±2.4	0.84±0.17	0.74±0.15	0.33±0.07	<42	**1 300**
sect. 3	12±1	1.4±0.3	1.0±0.2	17±0.3	0.32±0.02	0.64±0.13	0.3±0.04	36±8	**1 200**
sect. 4	2.7±0.3	0.27±0.05	0.31±0.06	3.0±0.3	0.19±0.04	0.21±0.04	<0.1	<25	**270**
Sect. 5	2.3±0.2	0.095±0.03	0.05±0.005	1.1±0.14	0.014±0.007	0.05±0.01	<0.05	<4	**230**
sect. 6	0.12±0.02	0.03±0.003	2.3±0.01	1.5±0.2	<0.003	<0.004	<0.005	<1	**14**
sect. 7	0.070±0.01	0.035±0,005	2,0±0,4	0,9±0,2	<0,004	<0,004	<0,008	<1,5	**8**
sect. 8	3.2±0.3	0.81±0.16	0.22±0.04	7.0±1.0	0.6±0.12	0.46±0.09	0.2±0.04	40±8	**330**
sect. 9	0.36±0.040	0.07±0.014	0.07±0.014	0.52±0.08	<0.026	0.027±0.005	<0.035	13±3	**40**
sect. 10	2.6±0.3	0.48±0.1	0.15±0.03	4.4±0.3	0.3±0.06	0.25±0.05	<0.07	<17	**260**
sect. 11	4.7±0.5	0.5±0.1	1.4±0.3	4.4±0.5	0.25±0.05	0.3±0.06	<0.06	<15	**475**
sect. 12	2.6±0.4	2.3±0.5	5.2±1.0	61±11	1.6±0.3	1.4±0.3	0.6±0.12	<32	**320**
sect. 13	220±20	8.3±1.7	2.6±0.5	62±9	6.1±1.2	6.2±1.2	2.1±0.4	250±50	**22 100**
sect. 14	0.9±0.1	0.12±0.02	0.21±0.04	0.9±0.2	<0.037	0.056±0.011	0.057±0.011	<12	**91**
sect. 15	4.2±0.4	2.3±0.02	0.76±0.01	15±5	0.5±0.01	1.2±0.03	0.05±0.002	45±5	**440**
sect. 16	20±1	6.5±1.3	1.8±0.4	100±3	3.8±0.8	3.5±0.7	0.11±0.02	140±30	**2 100**
sect. 17	1.8±0.2	0.24±0.02	0.085±0.005	2.8±0.3	<0.013	0.14±0.015	0.04±0.02	<6	**180**
sect 18	590±60	30±7	22±4	800±40	10±5	50±9	<14	<4000	**60 000**
Sect.19	1.4±0.2	0.13±0.02	0.14±0.03	1.9±0.1	<0.015	0.085±0.015	<0.03	<5	**142**
sect. 20	17±2	1.7±0.05	1.3±0.03	32±1	0.5±0.03	0.8±0.05	0.4±0.05	<24	**1 700**
Sect. 21	6.2±0.6	4.2±0.8	320±60	57±3	0.4±0.04	0.9±0.2	0.4±0.08	50±15	**710**
Sect.22	0.66±0.07	0.16±0.03	12±2	9.6±0.3	<0.01	0.05±0.01	<0.02	<4	**80**
Sect.23	0.31±0.03	<0.025	2.4±0.02	1.5±0.8	<0.005	0.009±0.005	<0.008	<2	**33**
Sect.24	0.79±0.08	0.4±0.01	32±6	17±1	0.01±0.005	0.075±0.05	0.035±0.01	<1.5	**100**
Sect.25	6.6±0.7	2.2±0.4	7.0±1.4	23±1	0.52±0.1	1.0±0.2	0.6±0.12	30±5	**684**
MSA	0.01	10	10	1	1 000	1 000	10 000	100 000	

* total indicator of radioactive contamination is the sum of rations of nuclides specific activities to their minimal significant activity

2.2. Estimation of vertical distribution of radionuclides

In order to determine the depth of radionuclide penetration in the soil and to estimate the volume of soil contaminated by radionuclides 3 spots, two of which are located on the opposite sides, near the boundaries of the test ground 4"A" (spot No.1 and spot No.17), and the third (No. 5) is located very close to the central part of the test ground, were chosen. The results of investigations are presented in the table (Table 3).

Table 3.

Specific activity of radionuclides in soil profiles of spots № 1, № 5 and № 7

Sampling point	Sampling depth, cm	Specific activity						
		Bq/kg						kBq/kg
		^{241}Am	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{60}Co	^{90}Sr
Sect. 1	0-5	140±50	170±20	<127	140±30	160±30	15±3	3 200±300
	5-10	570±60	530±50	160±30	390±70	190±40	18±4	5 700±600
	10-15	1 100±100	860±90	<96	610±120	240±50	28±6	7 300±700
	15-20	140±20	110±10	<57	80±20	<36	<3.0	4 000±400
	20-30	<18	7.0±2.0	<24	<6.0	<16	2.4±0.5	600±60
	30-40	<9.0	4.0±2.0	<20	<7.3	<12	<1.9	73±8
	40-50	<3.0	<1.0	<6.0	<2.0	<3	<0.7	8.1±1.3
	50-60	<2.5	3.0±1.0	13±3	<3.6	<4.1	<1.0	6.5±1.0
Sect. 5	0-5	100±20	90±10	84±17	44±9	<72	7.0±1.4	1 800±200
	5-10	<60	380±40	85±17	200±40	<68	11±2	3 000±300
	10-15	850±90	930±90	<57	560±110	240±50	29±6	2 900±300
	15-20	80±20	80±10	<44	64±13	38±8	4.0±0.8	1 400±100
	20-30	<22	<5.0	<31	<6.7	<30	<1.8	470±50
	30-40	<8.0	<3.0	<13	<6.0	<9.8	<1.96	36±4
	40-50	3.0±1.0	1.4±0.5	<4	<1.7	<2	<0.5	6.2±1.1
	50-60	<1.0	<0.7	<3.2	<1.3	<1.6	<0.4	4.8±0.9
Sect. 17	0-5	630±60	240±20	23±5	370±70	150±30	16±3	3 000±300
	5-10	<80	20±10	<110	60±10	<112	<7.4	2 700±300
	10-15	<32	8.0±4.0	<45	13±3	<31	<3	1 400±100
	15-20	<16	<3.0	<21	<5.7	<21	2.0±0.4	330±40
	20-30	<12	<4.0	<21	<7.3	23±5	<2.1	110±10
	30-40	<4.5	7.0±1.0	<6.0	4±0.8	5±1	<0.6	46±6
	40-50	<4.3	4.0±1.0	<9.7	<4.3	<6.0	<1.24	15±2
	50-60	6.0±3.0	5.0±1.0	<8	<3	<4	<1.0	14±2

Distribution of ^{137}Cs, ^{241}Am, ^{90}Sr, ^{154}Eu and ^{60}Co in depth of the soil cover in the studied spots is shown in the figures (Figures 3-7).

As one can see from the above figures, in spot No.17 specific activities of ^{137}Cs, ^{241}Am, ^{154}Eu and ^{60}Co sharply decrease along the depth of the soil profile and reach the plateau, which is indicative of radionuclides accumulation in the surface soil layer (0-10cm).

In the spots of local contamination No.1 and No.5 specific mass activity of ^{241}Am, ^{137}Cs и ^{154}Eu increases with depth to a depth of 10-15cm with further decrease in specific activities. A similar picture of ^{241}Am and ^{137}Cs distribution in the soil profile is observed in spot No.5. The difference between the distributions of ^{241}Am, ^{137}Cs and ^{154}Eu in the soil pro-

file in spots No.1 and No.5, on the one hand, and spot No.17, on the other hand, most likely indicates anthropogenic impact in the spots No.1 and No.5 either during WRA tests or after the tests.

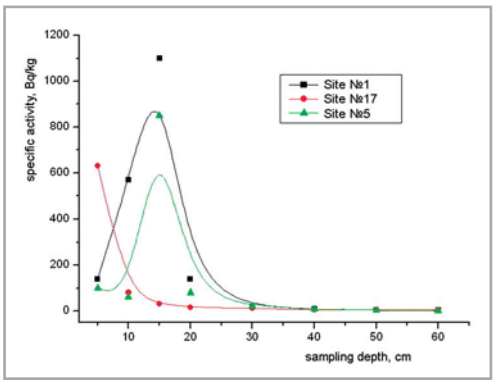

Figure 3. Distribution of ^{241}Am activity

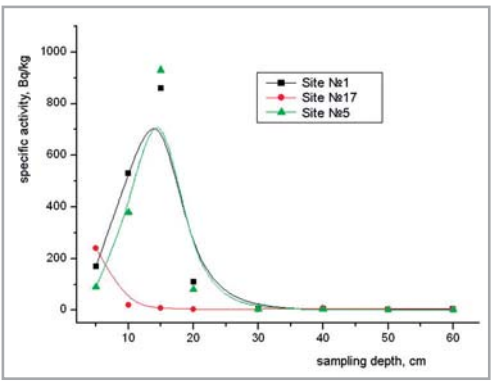

Figure 4. Distribution of ^{137}Cs activity

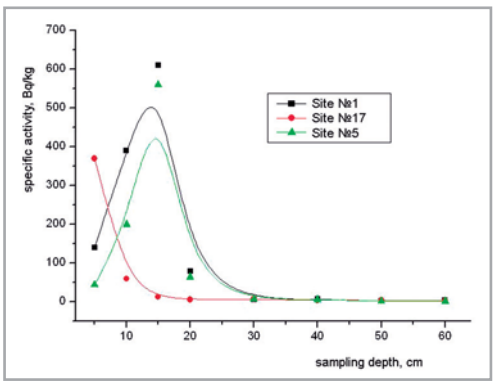

Figure 5. Distribution of ^{154}Eu activity

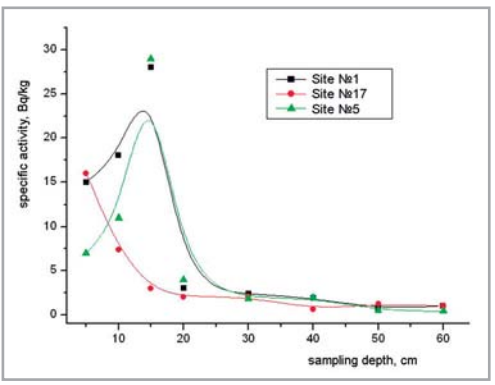

Figure 6. Distribution of ^{60}Co activity

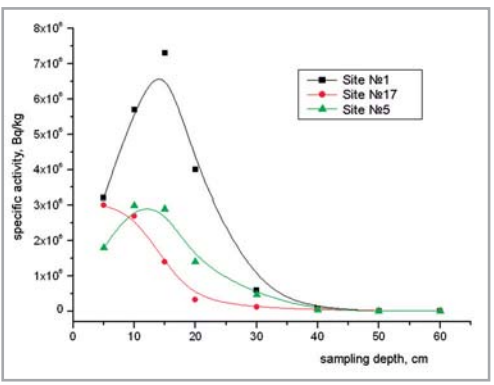

Figure 7. Distribution of ^{90}Sr activity

In the spot of local contamination No. 17 the main part of ^{90}Sr is concentrated in the upper organogenic layer and gradually decreases with depth along the soil profile (Figure 7). Such a distribution indicates high mobility of ^{90}Sr, mainly present in water-soluble and exchange forms. In the spots of local contamination No.1 and No.5, the ^{90}Sr specific activity increases with depth to a depth of 10-15cm and then sharply decreases.

It can be supposed that the environmental conditions during tests in spots No.1 and No.5 promoted the observed radionuclide distribution. For example, if tests were made during a heavy shower or spring slush, radioactive substances could penetrate with water flows deep into the soil. It is, certainly, very unlikely because of the presence of different geochemical barriers in soil [9, 10] and the ability of soil solid phase to simultaneously absorb cations, anions and neutral molecules [11], but, in principle, possible. For example, the paper [12] mentioned a nonuniform character of ^{90}Sr distribution in the soil cover of the test ground "Experimental field", where in some cases ^{90}Sr concentration in layers 10-15 cm and 15-20 cm was higher than that in the 5-10 cm layer.

However, an increased concentration of radionuclides ^{241}Am, ^{137}Cs, $^{152,154,155}Eu$ and ^{60}Co at the same depth (10-15 cm, Figure 8) as compared with the surface layer indicates artificial origin of the anomaly. Otherwise, due to the difference in the chemical properties of the above radionuclides their distribution would have a different character (natural). It is most likely that anthropogenic impact in spots No.1 and No.5 was caused by soil ploughing.

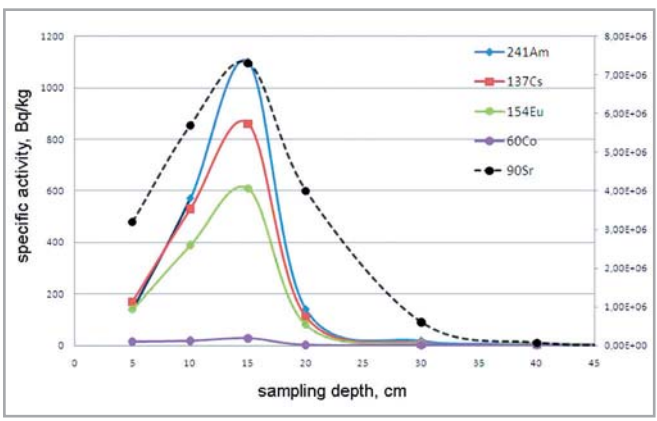

Figure 8. Radionuclide distribution in sector №8

In spots Nos.8 and 17 the depth of soil layer classified as SRW was about 30 cm. In case of soil reclamation in these sectors it would be necessary to remove 0.3 m^3 of soil of mass of about 480 kg (for ρ_{soil}=1,600 kg/m^3) from each square meter.

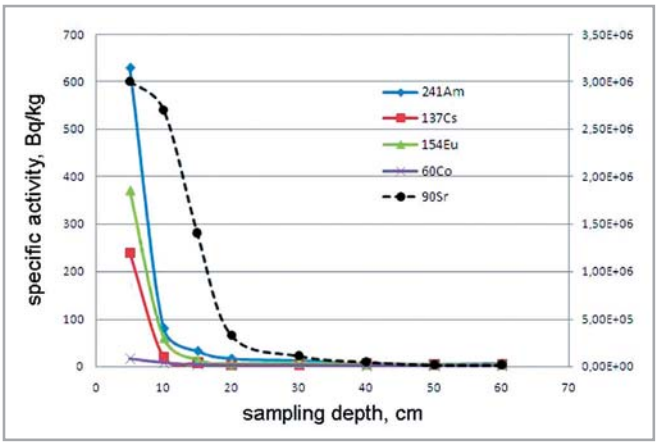

Figure 9. Radionuclide distribution in sector № 17

3. DISCUSSION OF THE RESULTS

In order to classify the revealed areas of radioactive contamination in terms of possible radiation sources, isotopic ratios were analyzed.

It was supposed that some spots were for EDR as a result of the same test. If such an assumption were confir EDR, it would facilitate, to some extent, the choice of further actions. For example, it would not be necessary to carry out further investigations in those areas.

The ratios of radionuclide activities to the ^{90}Sr activity in the upper layer (0-10cm) of the studied spots are presented in Table 4.

Table 4.

Isotopic rations in soil samples taken from the studied areas

Sector number	$^{239+240}$Pu	^{137}Cs	^{241}Am	^{154}Eu	^{152}Eu	^{155}Eu	^{60}Co
Sect. 1	180±30	23±3	11±2	5±1	1. 7±0. 4	2. 1±0. 7	0. 21±0. 07
Sect. 2	90±30	11±3	12±3	6±2	6±2	2. 5±0. 7	<0. 3
Sect. 3	140±14	8. 3±2. 4	12±4	5±2	3±0. 4	2. 5±0. 5	0. 3±0. 09
Sect. 4	111±23	12±4	10±3	8±2	7±2	<3. 7	<0. 9
Sect. 5	50±10	2. 2±0. 4	4±2	2. 2±0. 6	0. 6±0. 4	<2. 2	<0. 17
Sect. 6	1 300±400	2 000±330	25±7	<3	<2. 5	<4. 2	<0. 8
Sect. 7	1 300±500	3 000±1 000	50±14	<6	<5. 7	<11. 4	<2. 1
sect. 8	220±50	7±2	25±7	14±4	20±6	6±2	1. 3±0. 4
sect. 9	140±40	19±6	19±6	8±2	<7. 2	<9. 7	4±1
sect. 10	170±30	6±2	18±6	10±3	12±4	<2. 7	<0. 7
sect. 11	90±20	30±10	11±3	6±2	5±2	<1. 3	<0. 3
sect. 12	2 300±800	200±70	90±30	54±20	60±20	23±8	<1. 2
sect. 13	30±7	1. 2±0. 3	4±1	3±1	3±1	1±0. 3	0. 11±0. 03
sect. 14	100±30	23±7	13±4	6±2	<4. 1	6±2	<1. 3
sect. 15	400±200	18±2	55±6	30±3	12±1. 4	1. 2±0. 2	1. 1±0. 2

Sector number	$^{239+240}$Pu	^{137}Cs	^{241}Am	^{154}Eu	^{152}Eu	^{155}Eu	^{60}Co
sect. 16	500±40	9±3	33±8	18±4	20±5	0. 6±0. 1	0. 7±0. 2
sect. 17	160±30	5±1	13±3	8±2	<0. 7	2. 2±1. 4	<0. 3
sect. 18	140±20	3. 7±1. 1	5±2	8±2	2±1	<2. 4	<0. 7
sect. 19	140±30	10±4	9±3	6±2	<1. 1	<2. 1	<0. 4
sect. 20	200±30	7. 7±1. 1	10±1	5±1	3±0. 5	2. 4±0. 6	<0. 1
Sect. 21	920±140	5 200±1 500	70±20	15±5	6±1	7±2	0. 8±0. 3
sect. 22	1 500±200	1 800±500	24±7	8±2	<1. 5	<3	<0. 6
sect. 23	500±300	770±80	<8	3±2	<1. 6	<2. 6	<0. 7
sect 24	2 200±340	4 100±1 200	51±6	9±7	1. 3±0. 8	4±2	<0. 19
Sect. 25	350±50	106±33	33±10	15±5	8±2	9±3	0.45±0.12

Studying the isotopic ratios of radionuclides enabled us to detect areas with similar isotopic ratios for a range of elements from $^{239+240}$Pu to ^{60}Co (Figure 10). The areas with close isotopic ratios are marked as crosshatched regions of the same color. Such areas are located not only close to each other but also at large distances. In the second case close values of isotopic ratios only show similar composition of radioactive substances used in tests. The assumption that some closely located spots with radioactive contamination had been for EDR as a result of one test was not confir EDR because of different direction of axes of radioactive contamination.

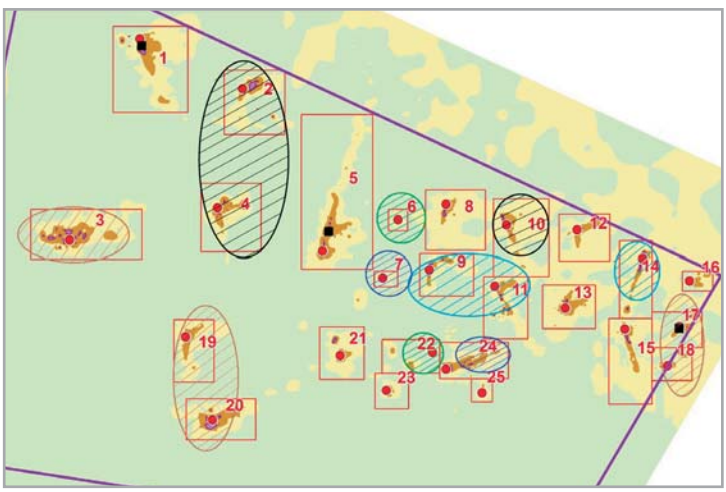

Figure 10. Areas of radioactive contamination with close isotopic composition for the whole series of considered radionuclides

There are also areas located close to each other but with different isotopic ratios. It is most likely that in these areas WRA tests of different composition were made or radioactive emissions of several tests were superimposed. It is also necessary to take into account close values of isotopic ratios in different groups, which makes it possible to refer them simultaneously to several groups.

CONCLUSIONS

- The levels of radioactive contamination of the studied areas differ from each other by several orders of magnitude. The main contaminating radionuclide is ^{90}Sr; however, a considerable contribution in the radiation hazard is made by plutonium isotopes. Reclamation of soil cover is to be started from the spots with maximal values of total radioactive contamination (spots No.18, No.13, etc.).
- There were discovered areas where reclamation had been made and areas with undisturbed soil cover, which undoubtedly changes the picture of radioactive contamination of soil cover. It is expedient to carry out research on vertical distribution of radionuclides in the other areas.
- The assumption that some closely located spots with radioactive contamination had been for EDR as a result of one test was not confir EDR. This enables us to make a conclusion that radioactively contaminated areas were for EDR as a result of independent WRA tests.

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ӘСКЕРИ РАДИОАКТИВТІ ЗАТТЕКТЕР СЫНАЛҒАН АЛАҢДАРДЫҢ РАДИОАКТИВТІ ЛАСТАНУ ДЕҢГЕЙІ МЕН СИПАТЫН ЗЕРТТЕУ

Осинцев А.Ю., Сәлменбаев С.Е.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Мақалада, 4 «А» ӘРЗ сынақ алаңының топырақ жамылғысындағы техногенді радионуклидтердің құрамының деңгейін анықтау бойынша келтірілген зерттеулер суреттеледі. Зерттеулер нәтижесінде, алаңның радионуклидті ластануы ^{90}Sr, ^{241}Am, $^{239+240}$Pu, ^{137}Cs, ^{152,154,155}Eu және ^{60}Co секілді радионуклидтердің орын алуымен шартталғаны анық болды, оның бастысы ^{90}Sr болып табылады. Радионуклидтердің тігінен таралуын зерттеуден, ^{137}Cs, ^{241}Am және ^{152,154,155}Eu негізгі белсенділігі топырақтың 20 см беткі қабатында жатқанын көрсетті. Сонымен қатар, топырақ бейінінің тереңдігі бойынша радионуклидтердің ауытқымалы түрде таралуы байқалған телімдер анықталды, олардағы зерттеліп жатқан радионуклидтердің максималды құрамы 10–20 см қатпарда бекіген. Изотопты арақатынасына зерттеу жұмысы жүргізілді, алынған изотопты арақатынасы мен кеңістіктік орналасуына байланысты, мүмкін деген көзден радиоактивті ластанған телімдердің бірі-біріне байланыстылығының мүмкін еместігін көрсетті.

Кілт сөздер: сынақ алаңы, радионуклидтік құрамы, радиоактивті ластану, радиоактивті қалдықтар, радионуклидтердің тігінен таралуы, радиоактивті ластанудың жиынтық көрсеткіші.

ИССЛЕДОВАНИЕ ХАРАКТЕРА И УРОВНЕЙ РАДИОАКТИВНОГО ЗАГРЯЗНЕНИЯ ПЛОЩАДКИ ИСПЫТАНИЙ БОЕВЫХ РАДИОАКТИВНЫХ ВЕЩЕСТВ

Осинцев А.Ю., Сальменбаев С.Е.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В статье описываются проведенные исследования по определению уровней содержания техногенных радионуклидов в почвенном покрове испытательной площадки БРВ 4 «А». В результате исследований выяснено, что радионуклидное загрязнение площадки обусловлено

присутствием таких радионуклидов, как ^{90}Sr, ^{241}Am, $^{239+240}$Pu, ^{137}Cs, ^{152,154,155}Eu и ^{60}Co, основным из которых является ^{90}Sr. Изучение вертикального распределения радионуклидов показало, что основная активность ^{137}Cs, ^{241}Am и ^{152,154,155}Eu находится в верхнем 20-см слое почвы. Вместе с тем, обнаружены участки с аномальным распределением радионуклидов по глубине почвенного профиля, на которых максимальное содержание изучаемых радионуклидов зафиксировано в слое 10-20 см. Проведено изучение изотопных отношений, которое показало невозможность привязки участков радиоактивного загрязнения друг к другу по возможному источнику поступления, исходя из полученных изотопных отношений и пространственного расположения.

Ключевые слова: испытательная площадка, радионуклидный состав, радиоактивное загрязнение, радиоактивные отходы, вертикальное распределение радионуклидов, суммарный показатель радиоактивного загрязнения.

УДК 577.4:504.064:539.16

GEOSTATISTIC-BASED DELIMITATION OF LOCAL RADIOACTIVE CONTAMINATION SPOTS COASED BY TESTS OF RADIOACTIVE WARFARE AGENTS

Ossintsev A.Yu., Mustafina E.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

In 2011, a detailed radiometric survey was conducted in the area of local pollution located on "4A" site of the Semipalatinsk Test Site, where warfare radioactive agents were tested. The goal of these studies was to determine the contamination spread and to assess its proliferation beyond the site boundary in dangerous quantities. Maximal contamination of the surface with β-emitting radionuclides outside the area was determined. The results of geostatistical processing of the data on surface contamination with β-emitting radionuclides are provided. The methodology selected for data processing can determine the border areas of contamination, both of tests with WRA and other similar experiments with dispersion of radioactive substances and assess the levels of contamination beyond certain boundaries.

Keywords: Semipalatinsk Test Site, warfare radioactive agents, "4A" site, β-emitting radionuclides, statistical data processing, geostatistical data processing, variation curve, spatial distribution.

INTRODUCTION

On the territory of Semipalatinsk Test Site (STS) besides main areas of contamination that are located in the areas of nuclear tests, there is another significant source of surface radioactive contamination that appeared in the result of conducting tests of radioactive warfare under the program on the former Soviet Union in the beginning of 1950-s [1]. The purpose of the program was testing practical use of weapons, determination of nature and efficiency of soil and air contamination and assessment of its impact on the human beings, animals, environment, military forces and their equipment. The tests included dispersal of warfare radioactive agents (WRA) by exploding single shells, bombing with bombs from airplanes, bombing territory with mortars or dispersal of military radioactive materials from the airplane. WRA were provided in liquid or powdered radioactive recipes produced either from radiochemical wastes or from specific materials that were irradiated by neutrons from operating nuclear reactor. Their specific activity varied from tenth of curie to several curie per liter.

Surveys of WRA test sites that were conducted by the Institute of Radiation Safety and Ecology under the National Nuclear Center of the Republic of Kazakhstan in different years revealed several fragments of metal constructions that were used with testing WRA as well as areas of local radioactive contamination that are characterized by high concentration of ^{90}Sr radionuclide in the environment comparing to lower concentration (3-4 times difference) of other long-lived radionuclides ^{137}Cs, $^{239+240}$Pu, ^{241}Am that are present on the territory of STS [2]. In total, there were identified over 40 objects and areas. Sizes of the areas delimitated in the result of the preliminary survey vary from 1 to 50 ha. Radioactive contamination with ^{90}Sr of the areas is up to $n \cdot 10^7$ Bq\kg [3, 4].

Radiation situation and nature of contamination at the territory of WRA test sites were well known by 2011. At present work is conducted to convert and transfer the northern part of STS that is located close to the site "4A" for public economical use. Considering the nature of contamination caused by testing military radioactive materials, i.e. local contamination spots, the matter was raised to evaluate probability of appearance of smaller spots with high activity of artificial radionuclides outside the test ground.

1. EXPERIMENT

To determine the nature of contamination proliferation in the areas of testing WRA, detailed radiometric survey of radioactive contamination of the area №5 was conducted; the area is located at the site "4A" used for WRA testing. This area was selected based on the previous surveys since this spot is characterized as the longest one among all areas and the one with maximum activity of artificial radionuclides (Figure 1).

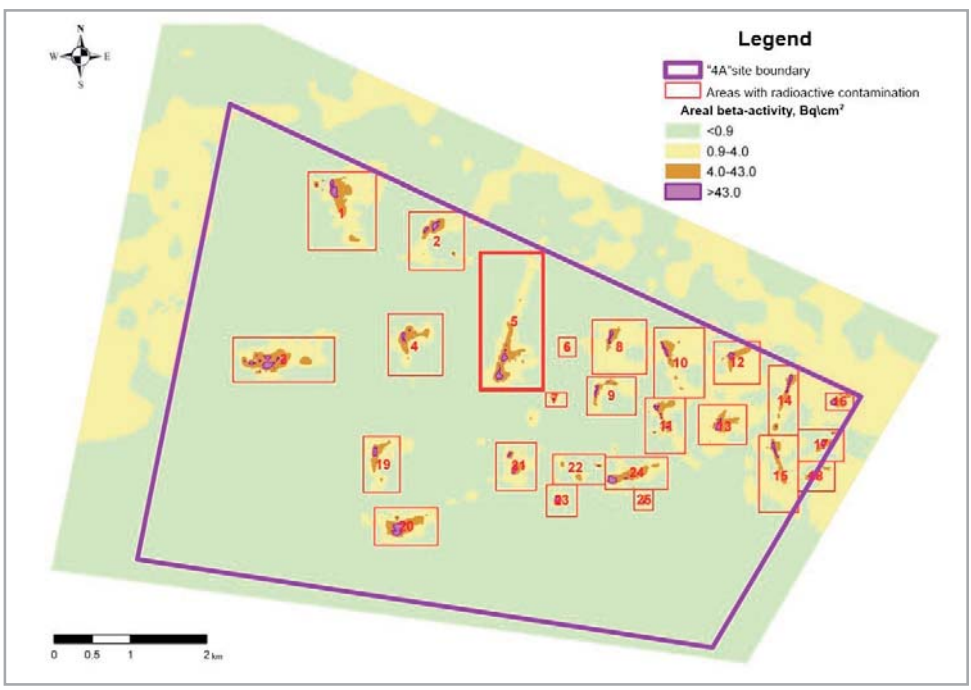

Figure 1. Location of area №5 with radioactive contamination at the RWA test site "4A"

Pedestrian β-survey was performed along designated profiles (1-14) with the step 1 m using dosimeter-radiometer RADIAGEM-2000 with detection sensor SAB-100 (in detection sensor scintillator ZnS(Ag) is used, that is sprayed on plastic scintillator 0.5 mm thick. Detector surface area is 100 cm^2, measurement range 0 to 526 Bq/cm^2, metering accuracy is ±15%). Control measurements of β-survey were performed with the same step at 1 m distance from the main profile. Survey map is showed at the picture below (Figure 2).

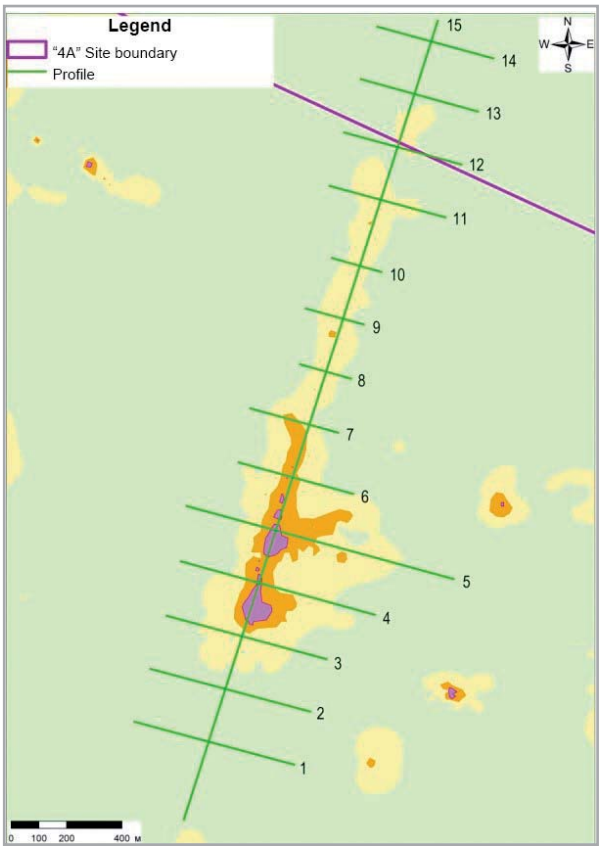

Figure 2. Survey map of area № 5

2. RESULTS

1.1. General results

Range of measured values of surface contamination by β-emitting radionuclides is from 0.4 to 248 Bq/cm^2.

In further analyses of the data, the average value of measurements along the main profile and control measurements were used as the actual value of surface contamination.

Analyzing variation curve for the whole massive (Figure 3), the conclusion can be made that the data does not belong to one general entity [5–7]. Considering existing data on the area of contamination it can be suggested that massive consists of two general entities – direct contamination due to test of WRA and adjacent territory with background values of radiation parameters.

To determine natural radiation background for the site "4A" we performed statistic processing of the data on surface contamination with β-emitting radionuclides below the selected level of 2 Bq/cm^2 (Figure 4).

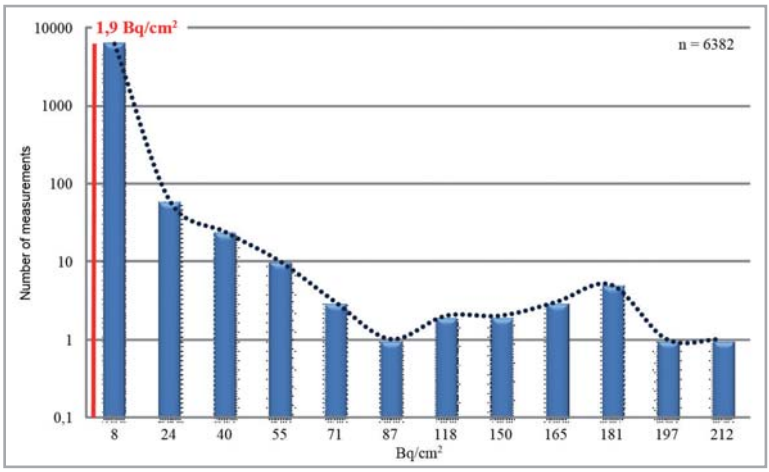

Figure 3. Variation curve of all measurements of surface contamination with β-emitting radionuclides

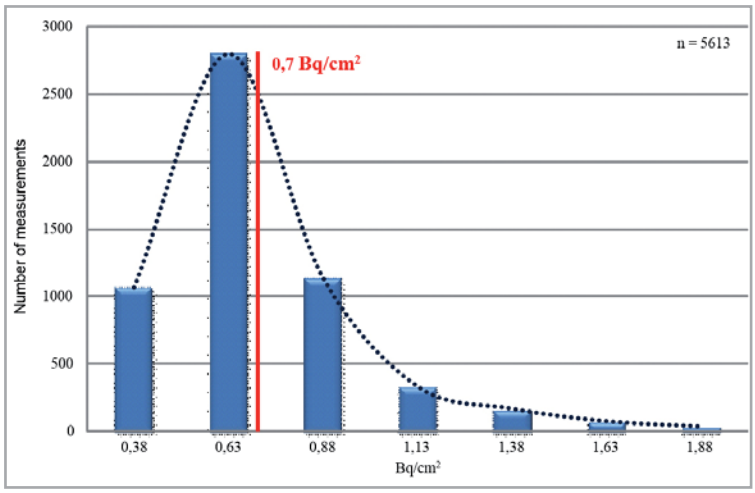

Figure 4. Variation curve of surface contamination measurements with β-emitting radionuclides up to the base level of 2 Bq/cm²

Variation curve of surface contamination measurements with β-emitting radionuclides up to "background" level has distribution nature close to logarithmically normal. Right asymmetry in the distribution shows presence of impact on conducted tests on distribution of β-emitting radionuclides. As natural "background" level for this territory we can accept average value of 0.7 Bq/cm².

Based on the obtained results, diagrams were built using measured values of surface contamination with β-emitting radionuclides (Figure 5, 6). Because of large data massive and variation in measurements for optimal visualization of diagrams for the profiles 1-14, data

approximation using linear filter for 20 locations was done. To build a diagram for the profile 15 actual data were used.

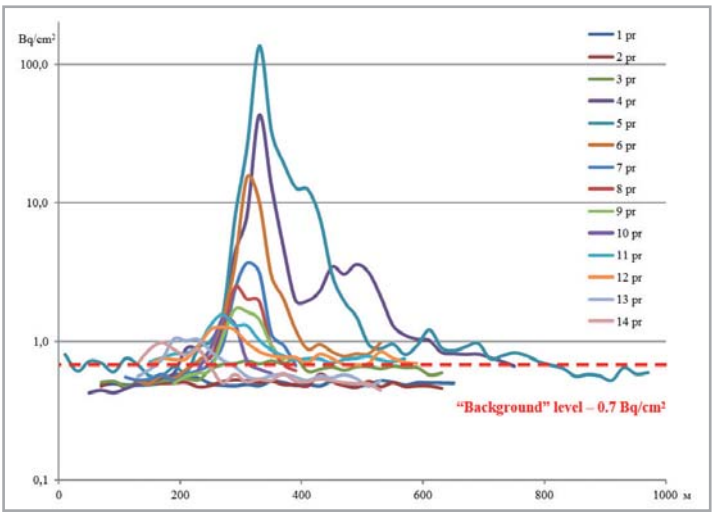

Figure 5. Distribution of surface contamination with β-emitting radionuclides by profiles

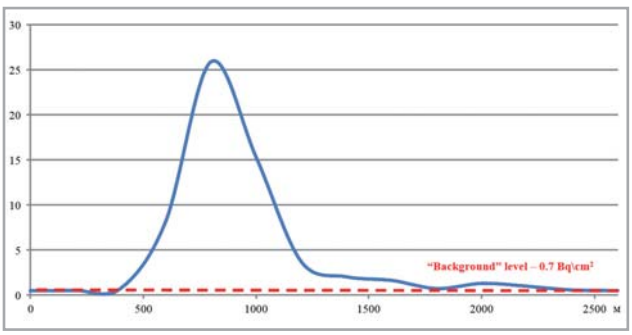

Figure 6. Distribution of surface contamination with β-emitting radionuclides at profile 15

Initial evaluation based on the analyses of diagrams with spread of surface contamination with β-emitting radionuclides along profiles allowed to make the conclusion that this contamination is of local nature. Area of contamination is about 300×850 m.

2.2. Data analyses

For detailed analyses the following diagrams of areal distribution were built based on actual data including the "background" level (Figure 7–21). To determine contaminated areas that are not connected to main contamination source visual analyses of diagrams was done. As the result of this analyses it was determined that for some profiles "background" level is

lower than the level for the whole data massive. For such profiles natural "background" levels were calculated and additional analyses performed to identify areas of contamination not connected with main contamination source. Contaminated areas were considered territories with radioactive parameters exceeding 15 % of calculated "background" level for the whole data massive.

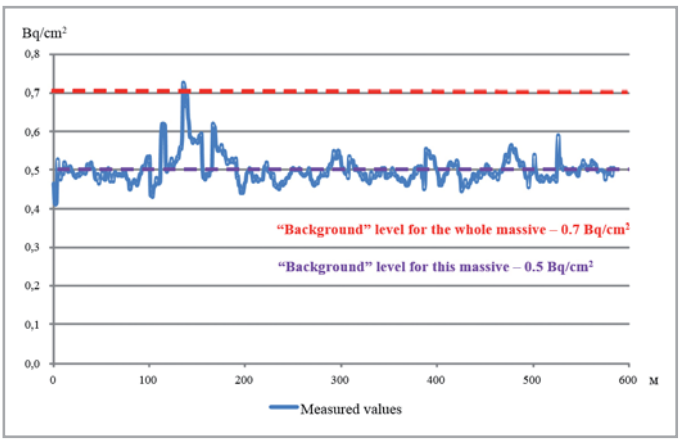

Figure 7. Distribution of surface contamination with β-emitting radionuclides for profile 1

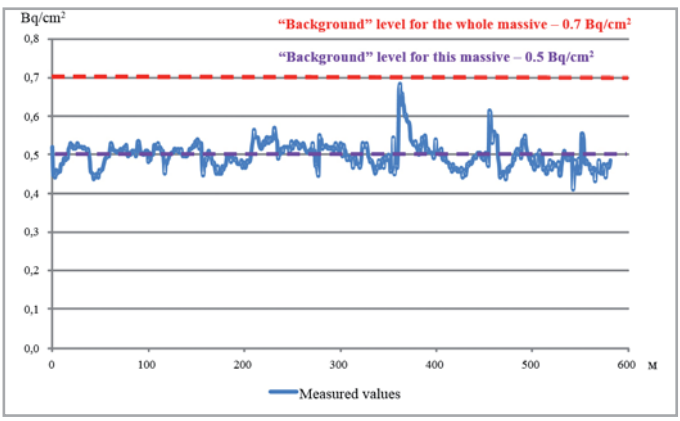

Figure 8. Distribution of surface contamination with β-emitting radionuclides for profile 2

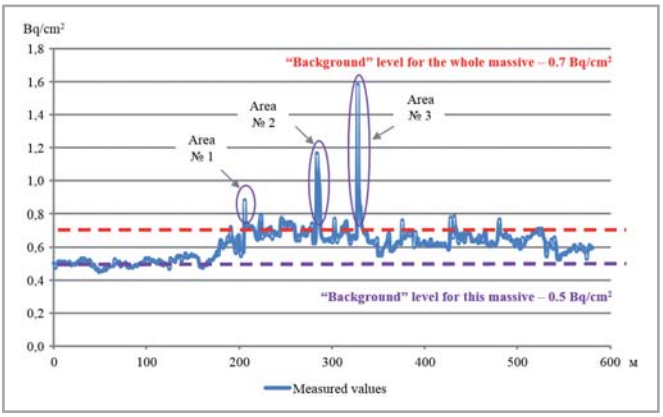

Figure 9. Distribution of surface contamination with β-emitting radionuclides for profile 3

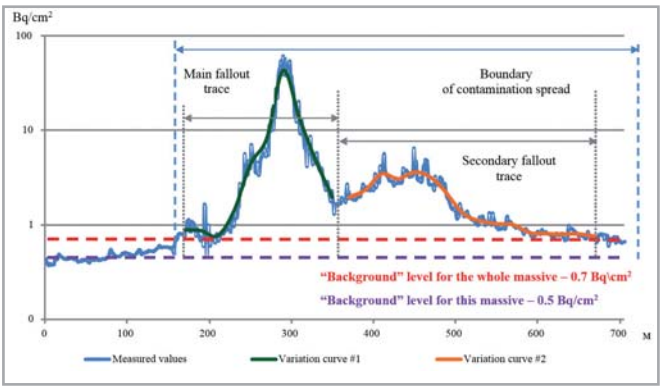

Figure 10. Distribution of surface contamination with β-emitting radionuclides for profile 4

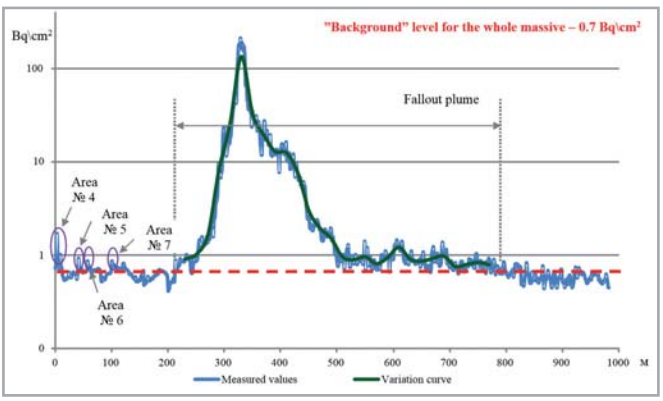

Figure 11. Distribution of surface contamination β-emitting radionuclides for the profile 5

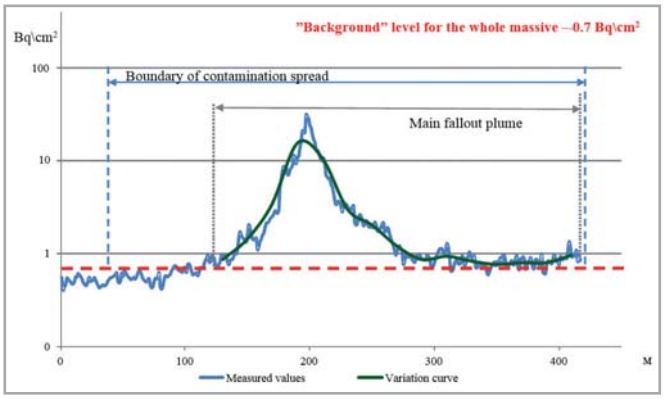

Figure 12. Distribution of surface contamination with β-emitting radionuclides for the profile 6

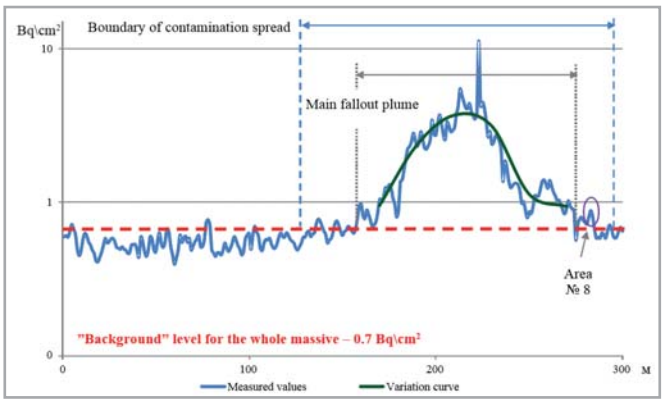

Figure 13. Distribution of surface contamination with β-emitting radionuclides for the profile 7

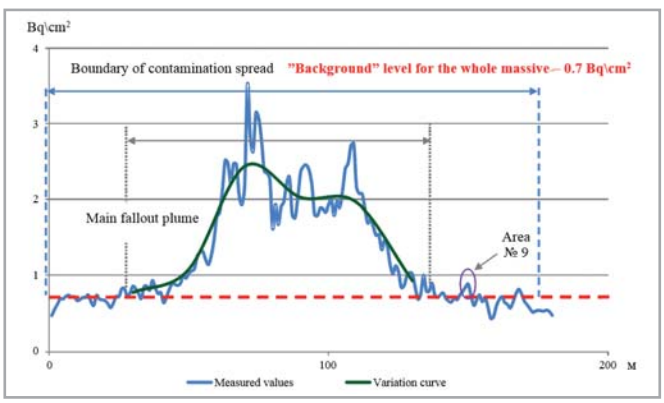

Figure 14. Distribution of surface contamination with β-emitting radionuclides for the profile 8

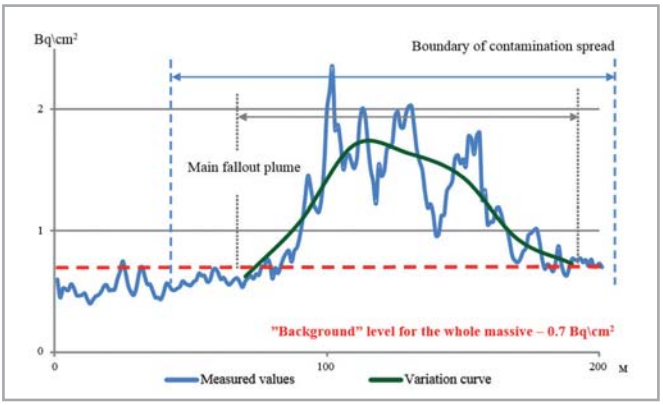

Figure 15. Distribution of surface contamination with β-emitting radionuclides for the profile 9

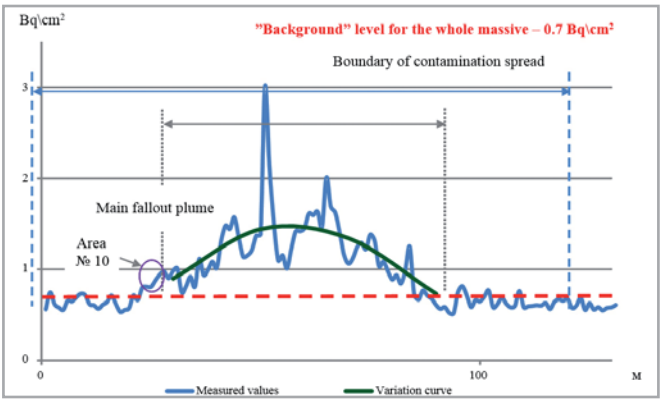

Figure 16. Distribution of surface contamination with β-emitting radionuclides for the profile 10

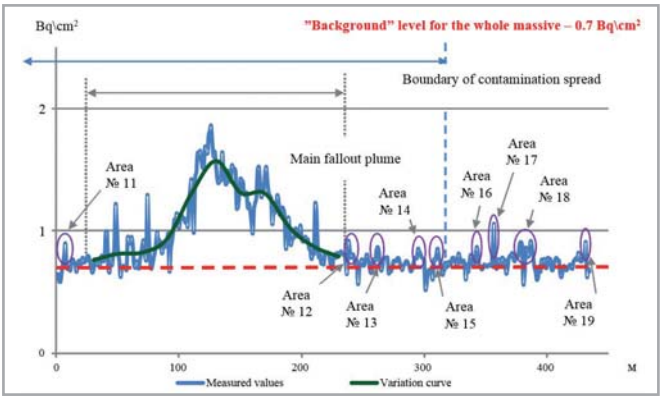

Figure 17. Distribution of surface contamination with β-emitting radionuclides for the profile 11

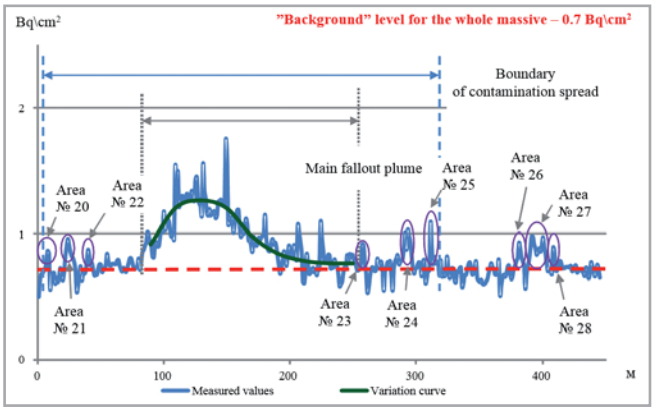

Figure 18. Distribution of surface contamination with β-emitting radionuclides for the profile 12

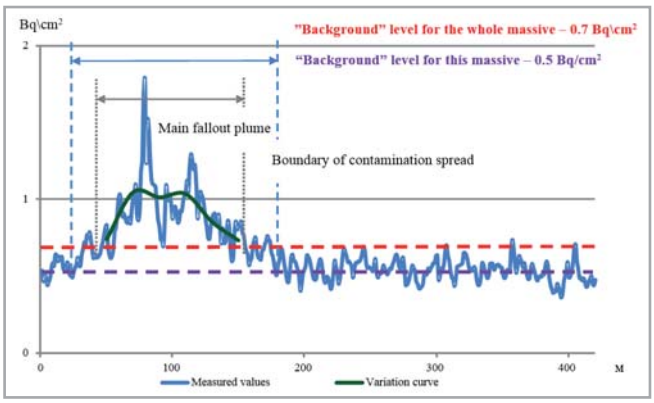

Figure 19. Distribution of surface contamination with β-emitting radionuclides for the profile 13

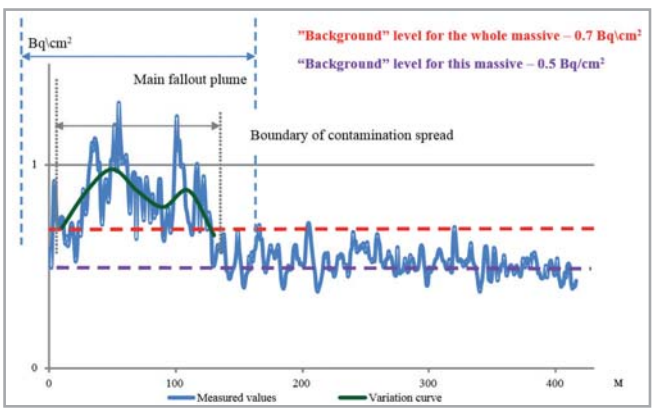

Figure 20. Distribution of surface contamination with β-emitting radionuclides for the profile 14

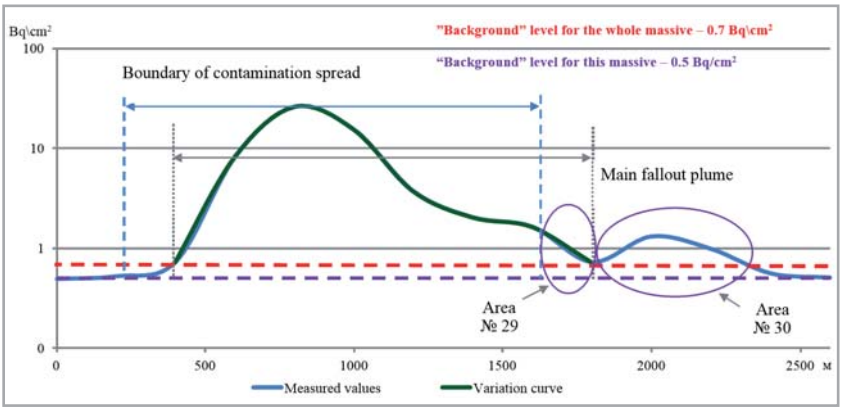

Figure 21. Distribution of surface contamination with β-emitting radionuclides for the profile 15

We took profile № 5 as an example of areal distribution of the surface contamination of β-emitting radionuclides since it is characterized by maximum radiation parameters and the biggest length. Analyzing nature of areal distribution along the profile № 5 the following conclusions can be made:

1. Clearly identified main route of radioactive fallout, width of fallout is about 300 m.
2. To the right of the main route there is an area with elevated readings of surface contamination with β-emitting radionuclides about 300 m wide that exceeds "background" level for up to 2 times. Supposedly, this area is formed by overlapping of traces from several tests or by displacement in distribution of radioactive materials from single test due to changes in direction of air masses at various heights.
3. The territory with "background" levels of surface contamination with β-emitting radionuclides is determined with fragment areas that are above the "background" levels. At the territory with background levels there are 4 areas identified with elevated levels of surface contamination with β-emitting radionuclides that exceed the "background" for 2.5 times.

Similar to the profile № 5, analyses of areal distribution of surface contamination with β-emitting radionuclides along all profiles were made and based on this analyses the following conclusions can be made:

1. Clearly identified main route of radioactive fallout that is 300 m wide and 850 m long. Spots with elevated readings above the natural "background" are registered at the area about 600x2,200 m (according to maximum readings).
2. At the territory with "background" level of surface contamination with β-emitting radionuclides, 30 spots were registered with elevated readings of β-emitting radionuclides. Cumulative information on the spots with elevated readings of surface contamination with β-emitting radionuclides is shown in the table (Table 1). Visually at the area № 5, 3 axes of radioactive materials dispersal can be determined (Figure 22).

Table 1.

Cumulative information on determined areas with elevated values of surface contamination with β-emitting radionuclides

Area	Profile	Area length, m	Maximum surface contamination with β-emitting radionuclides, Bq/sm^2
1	3	1	0,9
2	3	4	1.2
3	3	2	1.6
4	5	4	1.7
5	5	2	0.9
6	5	1	0.9
7	5	1.5	0.9
8	7	1.5	0.9
9	8	2	0.9
10	10	3	0.9
11	11	1	0.9
12	11	2	0.9
13	11	2	0.9
14	11	2	0.9
15	11	1	0.9
16	11	1	0.9
17	11	2	1.1
18	11	11	0.9
19	11	1	0.9
20	12	2	0.9
21	12	4	1
22	12	1	0.9
23	12	3	1.1
24	12	6	1
25	12	2	1.1
26	12	2	0.9
27	12	12	1
28	12	2	0.9
29	15	150	1.6
30	15	250	1.3

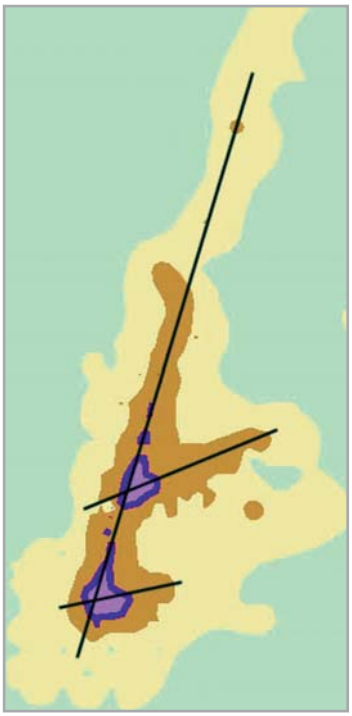

Figure 22. Radioactive contamination proliferation axis

2.3. Statistical processing of data

To statistically process the data and to determine nature of distribution of contamination, the areas were selected on the diagrams with profiles above the "background" level (variation curves of spatial distribution) (Figure 7–21). Variation curves of spatial distribution for the profiles 1-3 cannot be built as the levels of surface contamination with β-emitting radionuclides along these profiles remain at the "background" level. For the profiles 4-14 approximated data were taken using linear filter by 20 points. For the profile 15, actual data were used. For further statistic processing the length of contamination was taken as variable value of variation series and as frequency of occurrence – surface contamination with β-emitting radionuclides. To determine nature of distribution of surface contamination with β-emitting radionuclides, the average values (M) and average square deviations (σ) were calculated for each variation row using the method of weighted variations [8]. Then, equalizing of observed curves by the normal law was done and evaluation made of the difference between theoretical and observed distribution using the λ criterion [8–11]. Calculation results are shown in the table (Table 2).

Table 2.

Results of statistic data processing of selected variation curves

Variation curve	M, m	σ, m	λ
Profile 4	338	96	2.60
Profile 5	357	73	3.76
Profile 6	220	60	1.45
Profile 7	216	27	0.12
Profile 8	83	30	0.18
Profile 9	128	28	0.17
Profile 10	59	23	0.14
Profile 11	133	60	0.22
Profile 12	163	53	0.26
Profile 13	99	25	0.21
Profile 14	69	32	0.24
Profile 15	896	224	0.7

The difference between theoretical and observed distributions can be considered as random if observed criterion (λ) does not rich the required probability cutoff. For our evaluation, the criteria equal to 1.63 was selected (used for normal responsibility of analyses results). Thus, comparing calculated for our variation curves criteria λ with the probability cutoff (1.63), conclusions can be made that the distribution for profiles 6 to 15 has normal nature. In the profiles 4 and 5 the distribution is not normal. Deviation from normal law is related to the spots with higher values of surface contamination that was caused either by overlapping of traces from several tests or by displacement in distribution of contamination from single test due to changes in movement of air mass at various heights that is confirmed by visually identified 3 axes in the contamination distribution (Figure 22). In this case contamination is characterized by several general entities where each has its own distribution nature. To check this suggestion, variation curve for the profile 4 was split into 2 variation curves based on the visual analyses (Figure 10). For these variation curves we calculated the main characteristics (M and σ), equalized the observed curves by the normal law and calculated the λ criterion (Table 3).

Table 3.

Results of statistic data processing of selected variation curves

Variation curve	M, m	σ, m	λ
Profile 4, № 1	292	22	0.88
Profile 4, № 2	447	87	0.77

From the calculations, the conclusion can be made that both distributions has normal nature that confirms suggestion on overlapping of several general entities.

Since we did the analyses of spatial distribution, specific values M and σ are given in meters. Therefore, based on the calculations and data on the nature of distribution boundaries of local contamination area can be determined and assessment made that contamination above the selected "background" level will not go beyond the border of the surveyed area and equal 3.3 σ with probability 99% (for the profiles with normal law of distribution) (Figure 23).

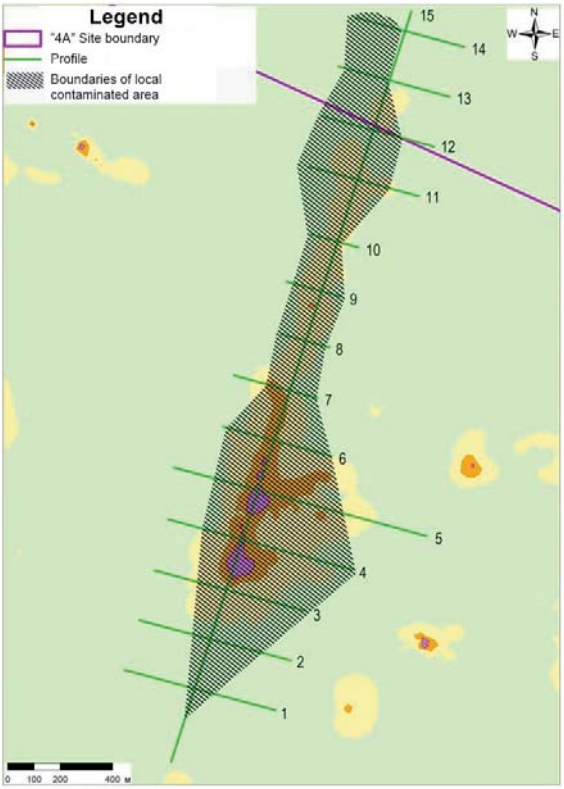

Figure 23. Assessed boundary of the local contaminated area

CONCLUSIONS

Thus, based on the results of the analyses, the conclusion can be done that spatial distribution of contamination spots at the site "4A" where radioactive warfare agents were tested has Gaussian distribution nature or close to it. Beyond the boundaries of contamination, 16 spots with elevated values of surface contamination were identified with width from 1 to 200 meters with maximum reading of surface contamination with β-emitting radionuclides 1.7 Bq/cm^2. Based on the conducted analyses it can be assumed that beyond the boundaries of the areas where WRA were tested there will be no contamination with β-emitting radionuclides at levels imposing hazards on population.

GENERAL METHOD OF DATA PROCESSING

Based on the conducted researches general method can be described to process data of the performed radiological survey of the contaminated areas that were formed by the tests of WRA and other similar experiments with dispersing of radioactive materials:

1. To determine general geometry parameters of the area (form of contamination, length, width).
2. To identify main profiles. For areas with circle form 2 perpendicular profiles can be used that are put across the spot with maximum contamination. For areas with prolate form to select one main profile that is put along the whole area and several perpendicular profiles based on the length of the area.
3. To determine "background" level for this area.
4. To identify variation curves above the "background" level.
5. To calculate average values (M) and average square deviations (σ) for each variation series.
6. To perform equalizing of observed curves as per normal law.
7. To evaluate differences between theoretical and observed distribution using criteria λ.
8. Based on the calculated M and σ, to identify boundaries of local contaminated area.
9. To analyze areas with elevated levels of radiation parameters beyond the defined area boundaries.

CONCLUSION

Conducted researches allowed identifying the nature of radioactive contamination distribution in one part of the test site "4A". The conclusion can be made that spatial distribution has Gaussian distribution nature or is close to it. Based on the nature of radioactive contamination, the evaluation of contamination proliferation beyond the boundaries of the area in dangerous quantities was made. Based on this evaluation, it can be confirmed that beyond the identified boundaries of the WRA test areas, there will be no contamination with β-emitting radionuclides at levels that impose danger on population.

Employed method of data processing allows to use it for identification of boundaries of contaminated areas formed during test of WRA and other similar experiments with dispersing radioactive materials. Use of this method allows not only to identify boundaries of radioactively contaminated spots but also to evaluate with high level of probability the contamination levels beyond the boundaries of the selected area.

Nevertheless, this method is optimal only for radioactively contaminated areas that are formed after a single test and that has only one trace of fallout. For areas that are formed by several test and fallout traces are overlapping it is required to conduct survey of radioactive contamination of the whole area to identify all possible fallout traces and further description of each identified trace.

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ГЕОСТАТИСТИКА ӘДІСІН ПАЙДАЛАНА ОТЫРЫП ӘСКЕРИ РАДИОАКТИВТІ ЗАТТЕКТЕРДІ СЫНАУ САЛДАРЫНАН ПАЙДА БОЛҒАН ЖЕРГІЛІКТІ РАДИОАКТИВТІ ЛАСТАНҒАН ТЕЛІМДЕРДІҢ ШЕКАРАЛАРЫН АНЫҚТАУ

Осинцев А.Ю. , Мустафина Е.В.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

2011 ж. Семей сынақ полигонының әскери радиоактивті заттектер сыналған "4А" алаңында орналасқан жергілікті ластанған телімге жіті радиометриялық зерттеу жұмыстары жүргізілді. Аталған зерттеулердің мақсаты радиоактивті ластанудың таралу сипатын анықтау және оның алаңның шекарасынан тыс жерге қауіпті мөлшерде шығуын бағалау. Телімнің шекарасынан тыс жерге β –сәуле шығарушы радионуклидтердің беткі ластануының максималды мәні анықталды. Беткі қабаттың β –сәуле шығарушы радионуклидтермен ластануына қатысты деректерді геостатистикалық өңдеу нәтижелері келтірілді. Деректерді өңдеу әдіснамасы ӘРЗ сынақтар өткізу барысындағы және басқа да радиоактивті заттектерді шашыратуға байланысты осыған ұқсас тәжірибелер барысындағы ластанған телімдердің шекараларын анықтауға және телімнің белгілі бір шекарасынан тыс жерлерге ластанудың таралу деңгейін анықтауға мүмкіндік береді.

Түйінді сөздер: Семей сынақ полигоны, әскери радиоактивті заттектер, "4А" алаңы, β-сәуле шығарушы радионуклидтер, деректерді статистикалық өңдеу, деректерді геостатистикалық өңдеу, вариациялық қисық, кеңістікте таралу.

ОПРЕДЕЛЕНИЕ ГРАНИЦ УЧАСТКОВ ЛОКАЛЬНЫХ РАДИОАКТИВНЫХ ЗАГРЯЗНЕНИЙ ОБРАЗОВАННЫХ ВСЛЕДСТИИ ИСПЫТАНИЙ БОЕВЫХ РАДИОАКТИВНЫХ ВЕЩЕСТВ С ИСПОЛЬЗОВАНИЕМ МЕТОДОВ ГЕОСТАТИСТИКИ

Осинцев А.Ю., Мустафина Е.В.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В 2011 г. проведены детальные радиометрические исследования на участке локального загрязнения расположенного на площадке "4А" Семипалатинского испытательного полигона, где проводились испытания боевых радиоактивных веществ. Целью данных исследований являлась определение характера распространения радиоактивного загрязнения и оценка возможности его выхода за границы площадки в опасных количествах. Определены максимальные значения поверхностного загрязнения β-излучающими радионуклидами за границами участка. Представлены результаты геостатистической обработки данных поверхностного загрязнения β-излучающими радионуклидами. Выбранная методология обработки данных позволяет определить границы участков загрязнения, как при проведении испытаний БРВ так и других аналогичных экспериментов по диспергированию радиоактивных веществ и оценить уровни загрязнения за определенными границами участка.

Ключевые слова: Семипалатинский испытательный полигон, боевые радиоактивные вещества, площадка "4А", β-излучающие радионуклиды, статистическая обработка данных, геостатистическая обработка данных, вариационная кривая, пространственное распределение.

УДК 577.4:577.391: 504.064:539.16

RADIOLOGICAL SITUATION IN IRTYSH PINE FOREST

Strilchuk Yu.G., Ossintsev V.S., Magasheva R.Yu.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

Many years of nuclear tests at the Semipalatinsk Test Site (STS) formed spots of radioactive contamination not only on the test site territory, but in the surrounding regions. One of these areas is a growing band of the Irtysh Pine Forest, located in the north-east of the test site.

The Irtysh Pine Forest is located on the right bank of the Irtysh River in the two regions of Kazakhstan – East Kazakhstan and Pavlodar Regions. The total area of the pine forest is 870.5 thousand hectares. The forest forming species – pine (Pinussilvestris). The forest is relict and has great ecological and socio-economic importance.

The main radiological consequences of the forest ecosystems radioactive contamination is accumulation of radionuclides in forest products, limiting its further use, internal and external exposure of the public and the staff involved in forestry. Unlike agricultural lands, which can use protective measures, changes in the content of radionuclides in the components of the forest are mainly due to natural factors. Due to the long time of their purification, the forest ecosystems for long become a source of radiation risk to the public and forestry workers.

Keywords: Pine Forest, first nuclear test, artificial radionuclides, soil profile, radiation situation.

SURVEYS OUTSIDE THE STS DURING NUCLEAR TESTS

At the time of the nuclear tests and after their termination, various studies were carried out that one way or another investigated the effect of nuclear tests on the environment, as well as the consequences of nuclear tests – nature and extent of radionuclide contamination on the STS areas and in adjacent areas.

Studies during the tests were carried out by the specialized units of the Ministry of Defense of the USSR and the Ministry of Medium Machine Building (military unit 52605; National Research and Development Design Institute of Industrial Technologies, Moscow; "Radium Institute" Nongovernment Organisation, St. Petersburg). The focus of studies was the military-industry research, radiation safety, and Radioecology.

The survey of the area adjacent to the STS, which was covered by the cloud from the first nuclear test as of August 29, 1949 that went over that area, was conducted just a few days after the test. To evaluate radiation situation, the radiation survey was arranged with the use of air and ground transport. During the survey, the airplane crossed the trace axis at least 15 times starting from the boundary of the Irtysh River. At the same time, the maximum gamma radiation dose was fixed at the height of the fly with georeferencing of this value in each section of the trace. Those who were involved in the survey noted that 300 km away from P-1 test site, when crossing the trace axis, sharp increase of radiation intensity was observed, and at greater distance from this site the increase of radiation intensity on the trace axis was minor and sort of "wash out" along its cross section. This was enough to identify and fix on the ground the location of the trace axis with the accuracy of ± 2.5 km [1].

We do not have any information about environmental compartment sampling at the beginning of the tests. However, the existing information about the trace boundary location from other ground nuclear tests shows that radiation surveys were conducted regularly. The first quantitative data on radionuclide concentration in plants and food that we could find in the literature were obtained in the period of 1956-1958. These studies were initiated "in connection with the appearance of potential danger from radioactive fallouts to the health of country population, the Council of Ministers of the USSR, starting from 1956, took measures to arrange control over the extent of radioactive contamination of the environment in the USSR…" [1]. Since that time, systematic sanitary-hygienic assessment of soil and vegetation radioactive contamination hazard has been performed. After 1958, as the radiochemical methods were introduced and spectrometric equipment appeared, the studies were initiated to determine the content of bio-hazardous radionuclides in various environmental compartments: strontium-90, cesium-137 and iodine-131. All these studies related, first of all, to food produced in the areas adjacent to the test field, and air, water and vegetation was also studied. The data on radionuclide concentration in the surveyed targets are mainly provided for the Dolon and Mostik settlements, and less often for Cheremushki, Bodene, and Semiyarka settlements. And there is practically no information about the levels of radioactive contamination of environment outside the populated areas in the forests.

STUDIES AFTER THE CLOSURE OF STS

Since 1990 the studies demonstrate the greatest scope with various organizations in Kazakhstan and other countries involved.

In 1990 and 1991, Aeromagnetic Field Party (Almaty), together with Aerogeophizika (Nikolayevka village), conducted the aero-gamma-spectrometry (AGS) at 1:1,000,000 scale covering almost the entire area of Semipalatinsk Oblast. As a result, a number of separate spots were identified with contamination level of over 0.1Ci/km^2 sporadically distributed throughout the survey area. At the time of the survey there were traces registered with ^{137}Cs contamination over 300-500 mCi/km^2 from nuclear explosions: on August 29,1949 – up to 12-18 km directly from the explosion epicentre (presumably); on September 24, 1951 – up to 55 –65 km; and on August 12, 1953 – up to 80-95 km. Away from these distances, the traces do not end up with an isoline and "go down" first into the regional and then into the global contamination [2].

One of the first comprehensive studies after the closure of the STS was performed within the framework of Region-1 R&D Program. In addition to AGS of the area, the residential areas near the test field were surveyed in details, plus the survey was conducted along the STS border. During the survey, which was conducted by experts of Radium Institute and other organizations, radiation was measured on the ground (exposure dose rate – EDR), and soil, vegetation and water samples were taken. Samples were analysed at the Radium Institute (St. Petersburg city) and in the Research Institute of Experimental Physics (Sarov city).

One of the findings that is of interest to our article was as follows: "The findings of the survey conducted in early 90s confirmed that the radioactive trace from the explosion of August 29, 1949 was located between Dolon and Mostik villages with 12 km between them" [3]. Numerical values of man-caused radionuclide concentrations in Dolon and Mostik were obtained. Unfortunately, no any information was received about the contamination of forests

along the trace of radioactive fallout from the first nuclear test and areas affected by radioactive contamination from other ground tests.

The same is stated in the report of SPF (Scientific and production firm) "Vershina" prepared in 1997, "the previously performed surveys of radiation situation are mainly limited by the contours of nuclear test field and the area directly adjacent thereto. Information about contamination of the rest of the area, first of all the man-induced radionuclide contamination connected with nuclear weapon testing, is highly fragmented, diverse, and quite often contradictory, and is mainly based on the findings of small-scale aero gamma-spectrometry. There are no any systematic targeted comprehensive studies covering all components of the natural environment" [2].

Geological forecasting and geological prospecting for uranium conducted in the STS area and representing the most comprehensive and systematic study of distribution of natural radionuclides and some artificial radionuclides can be called as the next stage in the study of radiation situation in the STS area

At the beginning of research works undertaken by the Institute of Radiation Safety and Ecology (IRSE) of the National Nuclear Centre of the Republic of Kazakhstan, there was information about measurements of surface activity and concentration of long-lived radionuclides in soil taken by other researchers near certain inhabited areas located close to the forests (Table 1) [4].

Table 1.

Data on measurements of surface activity and specific activity of long-lived radionuclides in soil

Author	Place	Surface Activity, kBq/m^2			Specific Activity, Bq/kg			
		^{137}Cs	$^{239+240}$Pu	^{90}Sr	^{137}Cs	$^{239+240}$Pu	^{90}Sr	^{241}Am
Hille, R. etal.	Mostik	-	-	-	5-60	-	4-12	0.9-1.6
Gastberger, M., etal.	Dolon, Mostik	0.3-7.9	0.14-9.7	0.5-6.1	1-34	0.7-41.6	n.d.-26	-
Dubasov, Yu., etal.	Dolon	0.74-11	0.04-30	0.52-11	-	-	-	-
Dubasov, Yu., etal.	Mostik	0.74-4.8	0.02-3.0	0.74-2.2	-	-	-	-
Deriglasov, W., etal.	Dolon	5.2-7.9	-	1.5-5.8	-	-	-	-
Yamamoto, M., etal.	Pine forest near Dolon	-	0.1-1	-	-	-	-	-
Sakaguchietal.	Dolon	0.8-10.3	0.5-14.3	-	2.8-71.4	1.7-94.9	-	-
Sakaguchietal.	Mostik	0.6-2.8	-	-	4.5-59.7	2.8	-	-
IAEA, 1998	Dolon	-	-	-	47-55	-	-	-
IAEA, 1998	Moldary	-	-	-	5-9	0.4-1.4	< 24	-
Notes: Global fallouts: ^{137}Cs – 1.8 kBq/m^2; ^{90}Sr – 1.1 kBq/m^2; $^{239+240}$Pu – 0.09 kBq/m^2								

As it is evident from the information obtained, the surface activity of radionuclides at the time of survey was mainly at the level of global fallouts. In some cases, the level of $^{239+240}$ Pu radioactive contamination of soil is ten times higher than the level of global fallouts.

One of the first works that allowed assessing the areal distribution of artificial radionuclides in the area adjacent to the STS from the northeast and partly covering the pine forests was the study performed at 1:1,000,000 scale. Studies were initiated in 1991 by Expedition No.39 of Volkovgeology KGGP (now – Volkovgeology JSC) as part of the national program of hydrolithochemical survey along the river flow.

It was designed to solve the problem concerning ecogeochemical assessment of contamination of large areas and regions in the USSR with radionuclides, pesticides, and some toxic elements. At the same time, subject to opportunities and specifics of radio-hydrolithochemical survey, the obtained data was also supposed to be used to solve the metallogenic problems, i.e. for the purpose of economic characteristic of mineral potential of raw material base of mining industry in different regions of the USSR along with the environmental assessment.

A range of works was defined based on "Methodical guidelines for regional hydrolithochemical survey along the small river flow at 1:1,000,000 scale" (Rudgeofizika NGO, L. 1990) and "Requirements to geological and environmental studies and mapping at 1 : 1,000,000 scale" (VSEGEINGEO, M. 1990). Field works in Semipalatinsk Oblast were completed in 1994, during which year the area of 75,800 km^2 was surveyed.

As a result of a range of field, test-and-methodological, analytical and office works performed by Expedition No.39 of Volkovgeology Geological Field Party, the data was received that characterized the distribution in the surveyed environments (surface water, and sediment) of principal natural and man-caused radioactive elements. Their background values were established, quality of potable water in a number of inhabited areas was assessed, and based on the area zoning according to the level of contamination, an effort was made to characterise the ecological importance of such contamination.

Following the analyses of bottom sediment samples, the areas with high contents of ^{137}Cs radionuclides were determined (Figure 1).

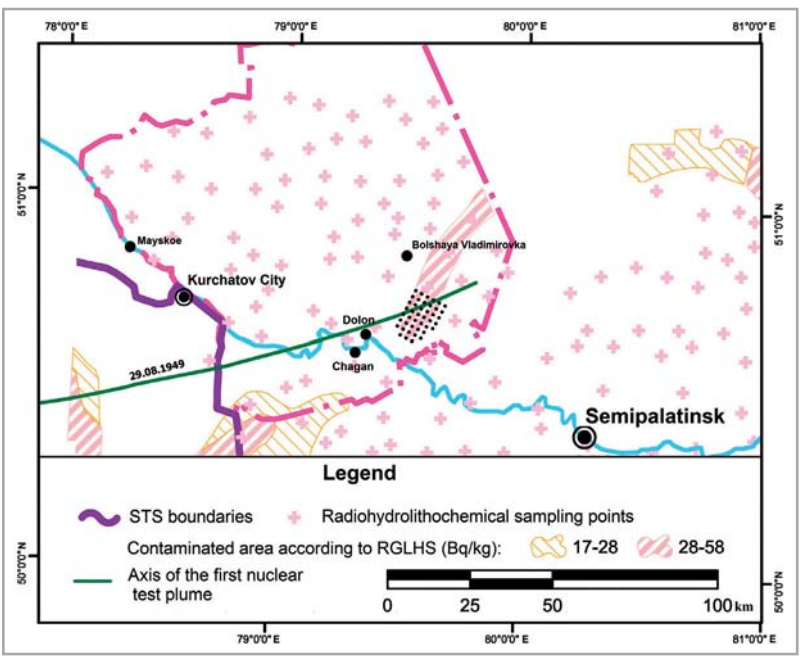


Figure 1. Layout of ^{137}Cs activity distribution in bottom sediments of small river flows

The areas of radioactive contamination shown in Figure 1 were identified as a result of combining the areas of surrounding micro-basins with high radionuclide concentrations in bottom sediment samples. In Beskaragai District an area was identified where caesium concentrations in bottom sediments were in the range of 28-58 Bq/kg.

We believe that although the use of such research techniques enables identification of areas (micro-basins) with excessive values of radiation parameters, it does not mean that such areas can be combined into areal structures as shown in Figure 1. The land plot with excessive concentration of ^{137}Cs is located east of Dolon and B. Vladimirovka villages, and its location does not align with the axis of radioactive fallout traces from the first nuclear test. The first nuclear test could have resulted in radioactive contamination of the area only within the southern part of the land identified. The northern part of the identified land was apparently contaminated by another ground nuclear test.

Unfortunately, at the time of those studies set out below, it was impossible to verify our assumptions, however our studies later confirmed the inaccuracy of combining the micro-basins based on the results of hydrolithochemical survey of this area.

Studies conducted by IRSE of NNC of the Republic of Kazakhstan in the Irtysh pine forests and presented in this article started in 2004 as part of the study of radiation situation in the Republic of Kazakhstan [5].

MEDIUM-SCALE FIELD SURVEY OF LOCAL RADIOACTIVE CONTAMINATED AREA

In 2004, Institute of Radiation Safety and Ecology, as part of the budget program "Provision of radiation safety. Study of radiation situation in the Republic of Kazakhstan" and by order of Volkovgeology JSC, performed works to examine the local areas of radioactive contamination that were previously identified based on the results of hydrolithochemical surveys along the small river flows. One of the areas was located on the radioactive fallout trace from the first nuclear test in Dolon village within the ^{137}Cs contaminated area with the specific activity in soil over 28 Bq/kg (Figure 1).

Radiological survey of the radioactive contaminated area involved radiometric measurements, environmental sampling followed by determination of specific activity of ^{137}Cs natural and artificial radionuclide.

Survey points are shown in the map (Figure 2).

In the course of radiological survey, 43 composite soil samples, 8 stratified soil samples, 4 grassland vegetation samples, and 3 needle litter samples were collected. Composite soil samples were collected at a regular evenly spaced grid of 2 × 2 km. The sampling method was "envelope" with the 10 m side. The area of composite sample is 300 cm^2, and sampling depth is 10 cm. In four points, which coincide with the soil sampling points, repeated soil samples were collected layer-by-layer at 0-5 and 5-10m depth at the same grid (from the same pits) by the "envelope" method. Vegetation samples were collected in the soil sampling places predominantly in grazing lands. The sample weight was at least 2 kg. In the forest, 7 samples of needle and leaf litter from 2 to 10 cm thick were collected from the area of 40 × 40 cm.

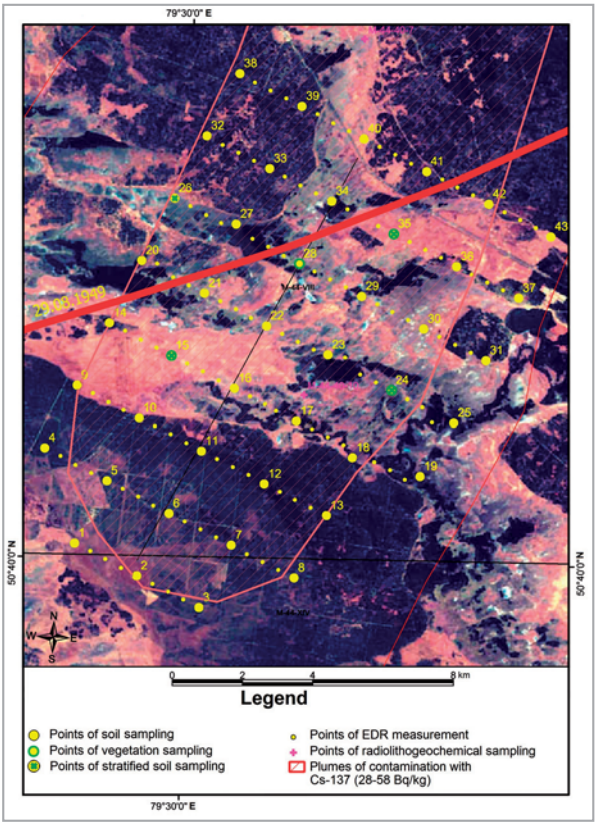


Figure 2. Soil and vegetation sampling points

In each spot sampling point, the equivalent dose rate of gamma radiation was measured on the soil surface and at the 1 m height. The spread in values of EDR within the envelope did not exceed 20 %. Average values of five points were recorded. In the points located along the profile with 500 m space between soil sampling points, EDR measurements were taken on the soil surface and at the 1 m height. The range of EDR measured in sampling points was from <10 to 12 μR/h, which corresponds to the background values for this area.

The efforts to identify any reliable regularity of EDR distribution depending on the location of the first nuclear test trace failed (Figure 3). Therefore, it would be apparently incorrect to rely on the EDR measurement results when singling out the radioactive contaminated areas in this land.

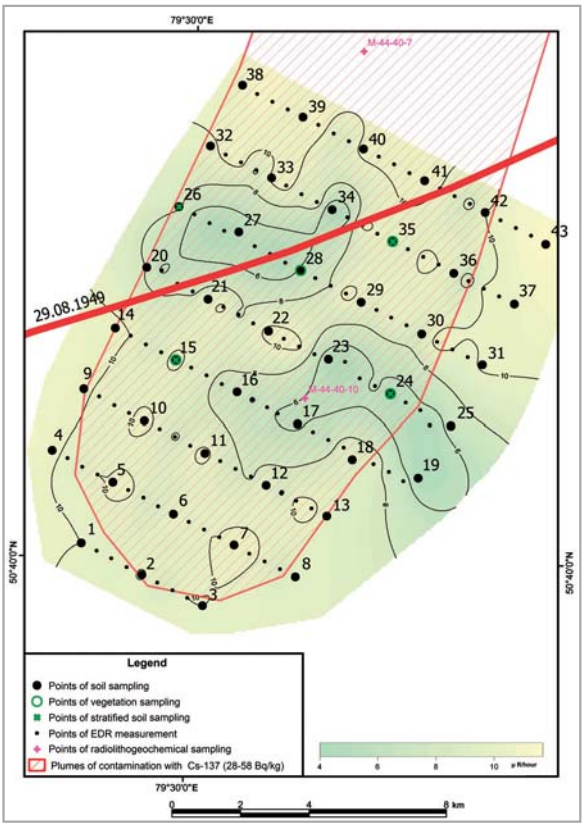


Figure 3. EDR distribution on the site

After the standard sample preparation (sieving and quartering of soil samples, and drying and cineration of vegetation samples), gamma-spectrometric analysis of the collected soil and vegetation samples were carried out. The results produced are set out in Table 2.

Table 2.

Concentration of ^{137}Cs in soil and vegetation

Sampling point	Sampling place	Specific activity of ^{137}Cs, Bq/kg				
		Soil	soil (0-5 cm depth)	soil (5-10 cm depth)	Grassland vegetation	Bark, pine needle*
1	Hay field	11±3	-	-	-	-
2	Coniferous forest	8±2	-	-	-	-
3	Coniferous forest	33±5	-	-	-	-
4	Coniferous forest	66±4	-	-	-	0.5±0.3*
5	Coniferous forest	14±3	-	-	-	-
6	Coniferous forest	18±4	-	-	-	-
7	Coniferous forest	34±3	-	-	-	-
8	Coniferous forest	30±4	-	-	-	-

Sampling point	Sampling place	Specific activity of ^{137}Cs, Bq/kg				
		Soil	soil (0-5 cm depth)	soil (5-10 cm depth)	Grassland vegetation	Bark, pine needle*
9	Coniferous forest	72±6	-	-	-	-
10	Coniferous forest	52±3	-	-	-	-
11	Coniferous forest	42±3	-	-	-	-
12	Coniferous forest	21±5	-	-	-	-
13	Coniferous forest	22±1	-	-	-	-
14	Coniferous forest	28±2	-	-	-	4.5±0.4 0.05±0.02*
15	Hay field	13±3	16±1	15±4	1.4±0.3	-
16	Hay field	38±3	-	-	-	-
17	Hay field	52±7	-	-	-	-
18	Aspen forest	21±2	-	-	-	-
19	Aspen forest	47±6	-	-	-	-
20	Aspen forest	69±6	-	-	-	-
21	Aspen forest	33±3	-	-	-	-
22	Aspen forest	34±3	-	-	-	-
23	Aspen forest	110±9	-	-		
24	Aspen forest	33±6	127±8	26±4	2.8±0.4	
25	Aspen forest	16±1	-	-		
26	Coniferous forest	66±7	76±8	16±2		
27	Aspen forest	96±8	-	-		
28	Aspen forest	140±9	-	-	1.9±0.2	
29	Aspen forest	32±2	-	-		
30	Aspen forest	44±3	-	-		3.2±0.5 (0.47±0.25 ^{241}Am)
31	Aspen forest	31±3	-	-		
32	Coniferous forest	34±2	-	-		
33	Coniferous forest	32±5	-	-		
34	Aspen forest	380±25	-	-		
35	Coniferous forest	15±4	11±2	17±4	1.7±0.1	
36	Coniferous forest	17±1	-	-		
37	Aspen forest	22±1	-	-		
38	Coniferous forest	26±4	-	-		
39	Coniferous forest	26±4	-	-		
40	Coniferous forest	25±5	-	-		
41	Coniferous forest	16±2	-	-		2.3±0.3
42	Coniferous forest	42±6	-	-		
43	Coniferous forest	16±4	-	-		

In the majority of the analysed samples, concentration of ^{137}Cs exceeds the global fallout background (GFB) that is about 15 Bq/kg [6]. Maximum concentration of ^{137}Cs is 380 Bq/kg, which exceeds the global fallout background ~25 times. Figure 4 shows the ^{137}Cs distribution in soil cover within the surveyed area, the specific activity in radiohydrolithochemical sampling is indicated in Bq/kg.

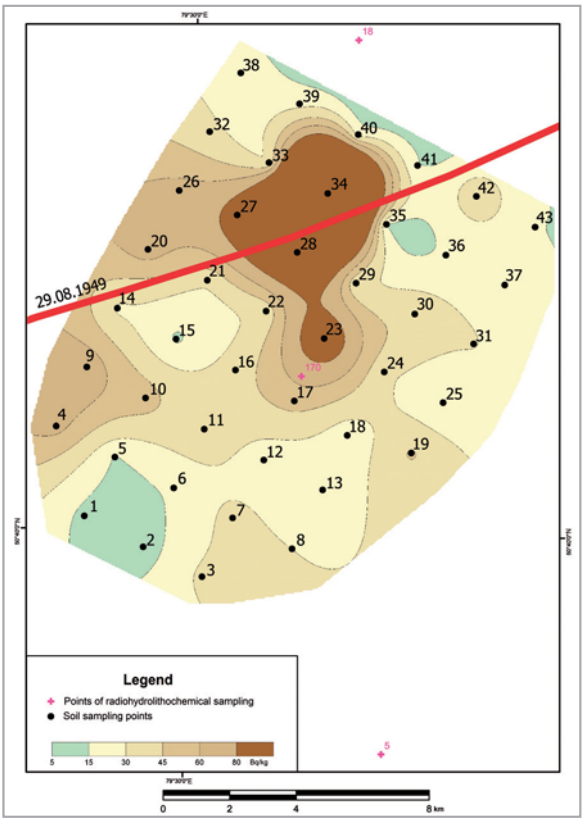


Figure 4. Map of ^{137}Cs distribution within the surveyed area

The distribution of ^{137}Cs within the surveyed land that covers the area of about 35 km^2 is uneven (minimum and maximum values differ almost 50 times). An area was discovered with the well-defined excessive concentration of ^{137}Cs in soil registered in several nearby points (23, 27, 28, and 34). There are also areas with the background values of ^{137}Cs. Such radionuclide distribution is, first of all, conditioned by irregular fallouts from radioactive cloud, as well as migration processes that are both natural and the result of reforestation. Distribution of ^{137}Cs along the depth of soil horizon (0-5, 5-10 cm) in the points where its concentration is at the level of GFB (point 15, point 35) is uniform. The variance in ^{137}Cs concentrations in the repeatedly collected soil samples is at the level of measurement method error. In the points where excessive concentration of ^{137}Cs is observed (point 24, point 26), its concentration in the upper 5 cm soil layer is 5 times higher than in the lower layer.

Concentration of ^{137}Cs in the grassland vegetation is one order less than in the soil layer of 5-10 cm (accumulation factor K_n is 0.1) in all three samples where the data on the layered distribution of ^{137}Cs in soil is available. Of course, this data is insufficient to draw final conclusions, however, such dependence might be conditioned by the location of the main root system particularly in this part of soil layer (5-10 cm). Occasional data was also received on ^{137}Cs concentration in the pine needle and bark of softwood and hardwood trees

(Table 3). Concentration of ^{137}Cs radionuclide is one order (6-14 times) less than in soil, and in the pine needles – two orders less. ^{241}Am radionuclide was registered in the bark of hardwood tree (aspen). No information about the age of the tree was specified, therefore in case of entry of this radionuclide through the bark, plutonium isotope presence can be also expected in the bark. In case of ^{241}Am entry through the root the question about plutonium isotope concentrations remains open.

A sand component was selected from the forest leaf litter samples. Samples of vegetation and sand component of litter were also analysed for artificial radionuclides (Table 3). Unfortunately, gamma-spectrometry of vegetable and sand fraction was carried out in one sample only (point 4), as to other samples the analysis, for different reasons, was performed either on the vegetation or on the sand fractions.

Table 3.

Gamma-spectrometry of soil and forest leaf litter samples

Sampling point	Place of sampling	^{137}Cs specific activity, Bq/kg			Notes
		Soil	Litter (vegetable component)	Litter (sandy component)	
4	Forestry	66±4	89±4	251±8	2,6±1,2 (^{241}Am in vegetation part of litter)
14	Forestry	28±2	63±3	-	
41	Forestry	16±2	31±3	-	
18	Aspen forest	21±2	-	105±5	
28	Aspen forest	139±9	-	78±7	
37	Aspen forest	22±1	-	48±3	
38	Forestry	26±4	-	235±9	

^{137}Cs concentration in the vegetation component of needle litter is 1.5-2 times higher than in the underlying layers of soil, and in the sandy component of litter (one sample only – p.4) the ^{137}Cs concentration is higher than in its vegetation component. In the same litter sample, ^{241}Am radionuclide concentration was found, which might evidence the presence of $^{239+240}$Pu radionuclides. ^{137}Cs concentration in the sandy component of litter is 2-10 times higher than in the underlying layers of soil, except for point 28 where the concentration of ^{137}Cs in soil is twice higher than in the sandy component of the litter. Based on the fact that in most cases concentration of ^{137}Cs is higher in the litter than in the soil, we will assume that this is the main type of radionuclide distribution in the soil cover. Such distribution can be explained by the processes that occur during the fallout from the atmosphere. The forest leaf litter is the part of forest ecosystem which collects the most of the man-caused contamination. In case with the radioactive fallout from nuclear explosion cloud the forest leaf litter contamination occurred in two ways: radionuclide fallout from the atmosphere directly onto the soil surface (forest leaf litter) and formation of forest leaf litter on account of the fall of contaminated pine needles and leaves. Further, in the course of radionuclide migration the most of radionuclides (depending on their chemical properties) accumulate in the litter.

STUDY OF RADIONUCLIDE IN-DEPTH DISTRIBUTION IN SOIL

The second objective of this study was the evaluation of radionuclide distribution within the studied area (radioactive contaminated area) along the depth of soil profile. The profile 25 km long comprising nine research fields (soil profiles) was placed on the right bank of the Irtysh River from the coastal area towards the trace of radioactive fallouts determined by the hydrolithochemical surveys (Figure 5).

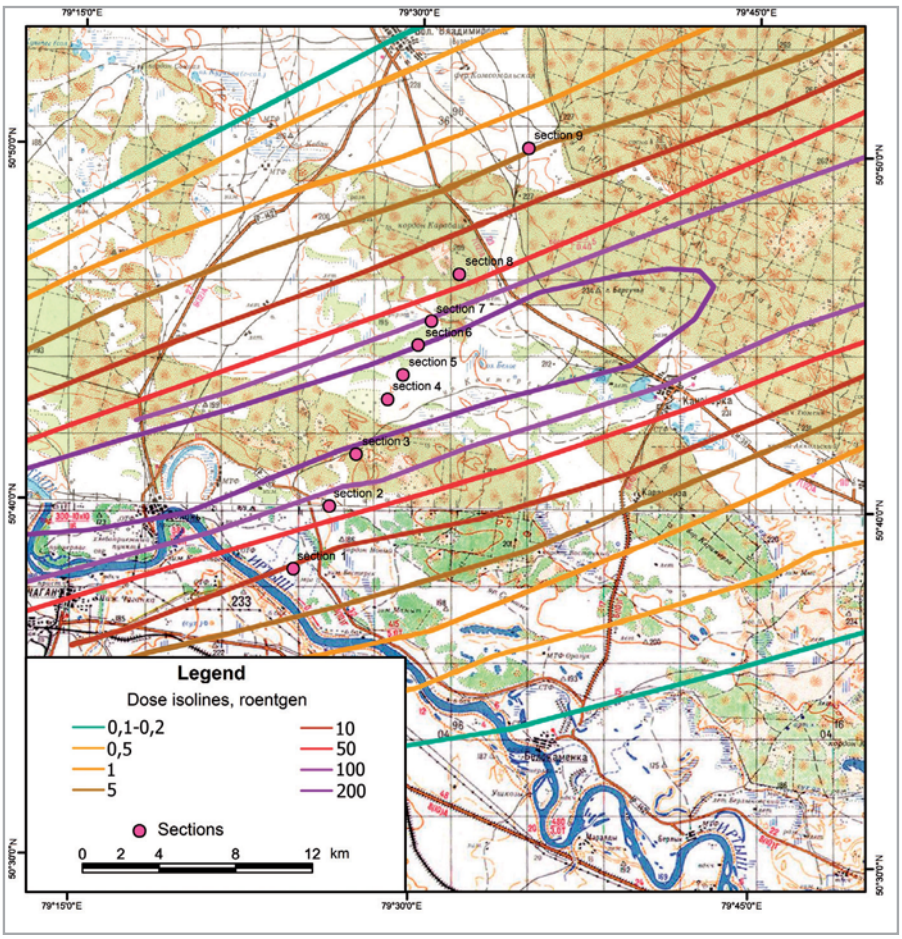


Figure 5. Layout of soil cross sections

This profile crosses the main landscapes of the right bank. Fields 1 and 2 are within the terrace above flood-plain of the Irtysh River of Irtysh valley-meadow area, according to the natural zoning [7] in the contour of $К_{л2}$ · Сн^{ск} meadow-brown ordinary together with meadow-steppe solonchak-like average alkali soil (20 %). Field 2 is located on the gentle slope of the valley side of the Irtysh River in the soil contour ЛГ$_2^{зс}$ · Сн$_л^{ск}$ · Ск$_л$ - meadow dark

salted lumpy in combination with meadow solonchak-like alkali soils (20%) and meadow solonchak (20%).

Fields 3-9 are located within the Semipalatinsk plain and hummocky sandy forest area and laid in various terrains and soils. Fields 3 and 8 characterize the soil contour $Пр^3 + К_2^{гв} + СД_2$ – pine forest plain sands, sometimes hilly, registered with dark brown deep effervescent sands of average thickness (20%) and in combination with turfy forest solod soil (10%). Field 4 is located in the contour of $К_2^{гв}$ – dark brown deep effervescent moderately thick and thick, Field 5 – in the contour of $ЛГ_2^{гв}$ – meadow dark deep effervescent lumpy, Field 6 – in the contour of $ЛГ_2^{к}$ – meadow dark carbonate lumpy, Field 7 – in the contour of $Б_л$ – meadow boggy, Field 9 – in the contour of $К_2^{гв}$- dark brown deep effervescent moderately thick and thick.

Composite vegetation samples in 2 replicates of 2 kg each were collected on each field, their species composition is described, soil profile is established, genetic horizons are described and soil samples area collected there for radionuclide analysis. Distribution of soil profiles and their intervals are presented in Table 4.

Table 4.

Distribution of soil horizons and stratified samples in the depth

Layer	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8	Section 9
	Depth, cm								
$А_д$		0-6			0-2		0-12		
$А_1$	0-13		0-3	0-2		0-2	12-24	0-3	0-3
$А_2$	13-34	6-13	3-14	2-11	2-8	2-10		3-15	3-18
B							24-55		
B_1		16-32	14-31	11-22	8-16	10-42		15-42	18-57
B_2		32-54	31-70	22-54	16-42	42-87			57-72
B_3				54-76	42-95				
BC		75-115	70-110					42-125	72-106
$B_{сн}$	34-100								
C		54-75		76-112	95-110	87-100			

Based on the field descriptions, lithological profile is composed along the trace line consisting of the above 9 soil cross sections (Figure 6).

As the Figure shows, the profile crosses the main landscapes of the Irtysh plain and Irtysh River valley. So, deep effervescent thin humus chestnut zonal soils, which are typical for wide ridges that separate ribbon forests; forest sands that are spread under the pine woodland; and meadow-boggy soils developed in depressions of ribbon rests were described and sampled. The meadow-salted soils on the valley side and meadow alkali soil in the terrace above flood-plain in the Irtysh River valley were described. Under the conditions when the flows are regulated by water reservoirs, these fields are not exposed to flooding, which resulted in soil salinization in the valley.The data obtained from cross-spectrum analysis is shown in summary Table 6.

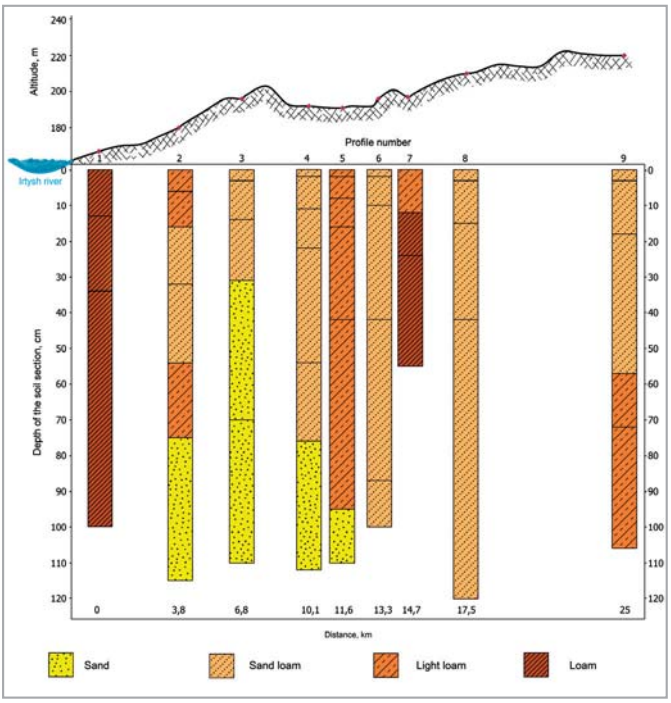


Figure 6. Lithological Profile

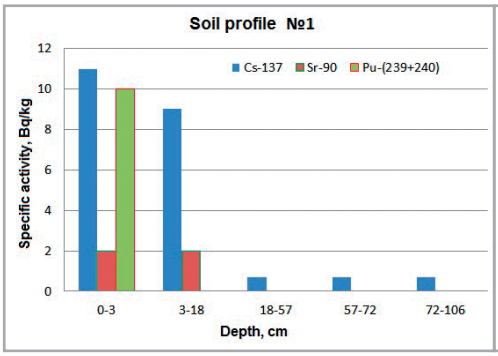
Table 6.

Radionuclide concentration in the soil-vegetation ecosystem in research fields Nos. 1-9

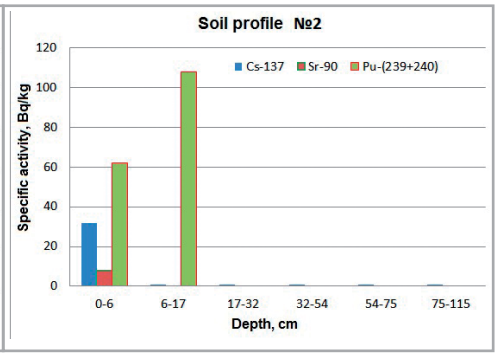
Place of sampling	Description of plants, research field	Depth of soil sampling, cm	Man-caused radionuclide concentration			
			^{137}Cs	^{137}Cs, repeated	^{90}Sr	$^{239+240}$Pu
Irtysh river terrace, wasteland	Wheat grass, worm-wood, anabasis-salsa		35±1	-	-	-
	Soil section 1	0-13	12±2	-	41±9	5±1
		13-34	<0.7	-	-	-
		34-100	<0.7	-	-	-
Terrace slope, deposit	Meadow-steppe grain varieties		0.8±0.2	-	-	-
	Soil section 2	0-6	41±3	-	8±3	62±15
		6-17	<0.7	-		108±6
		17-32	<0.7	-		
		32-54	<0.7			
		54-75	<0.7			
		75-115	<0.7			
Clearing in forest, thin forest	Steppe miscellaneous herbs		8.1±0.3			
	Soil section 3	0-3	39±2	32±2	<2	120±35
		3-13	13±2	11±1	4±2	40±10
		13-31	<0.7			57±8
		31-70	<0.7			
		70-110	<0.7			

Place of sampling	Description of plants, research field	Depth of soil sampling, cm	Man-caused radionuclide concentration			
			^{137}Cs	^{137}Cs, repeated	^{90}Sr	$^{239+240}$Pu
Clearing in forest, clear-boled forest	Dry steppe miscellaneous herbs		25±1			
	Soil section 4	0-2	11±2	13±1	<2	30±8
		2-11	20±2	18±2	5±2	80±30
		11-22	16±2	14±1	<2	45±11
		22-54	6±1			65±6
		54-76	<0.7			
		76-112	<0.7			
Clearing in forest, depression slope	Meadow miscellaneous herbs		27±1			
	Soil section 5	0-2	60±4	44±2	30±7	360±75
		2-8	31±3	21±2	20±5	56±12
		8-16	9±1		11±3	185±18
		16-42	<0.7			
		42-95	<0.7			
		95-110	<0.7			
Clearing in forest, depression slope	Meadow and steppe miscellaneous herbs		12.1±0.4			
	Soil section 6	0-2	112±4	95±3	44±9	310±65
		2-10	37±3	33±1	27±6	135±30
		10-42	<0.7			3.4±1.6
		42-87	<0.7			
Clearing in forest, bog	Bog-meadow miscellaneous herbs		79±1			
	Soil section 7	0-12	51±4		9±3	48.8±8.4
		12-24	9±2	7±1	<2	180±40
		24-55	<0.7			8.5±2.6
Clear-boled forest, forest meadow	Meadow and steppe miscellaneous herbs		43±1	-	-	-
	Soil section 8	0-3	33±2	-	<2	14±5
		3-15	3.4±0.7	<0,8	<2	130±30
		15-42	<0.7	-	-	8.2±2.6
		42-125	<0.7	-	-	-
Clearing in forest, hey-field	Meadow and steppe miscellaneous herbs		77±1	-	-	-
	Soil section 9	0-3	11±2		<2	10±4
		3-18	9±2		<2	
		18-57	<0.7			
		57-72	<0.7			
		72-106	<0.7			

Radionuclide distribution into the depth of soil horizon is also shown in Figure 7 (a – i).



a)



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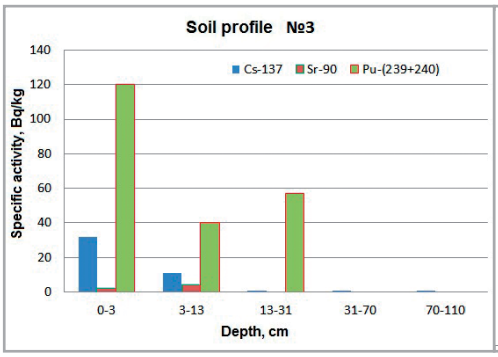

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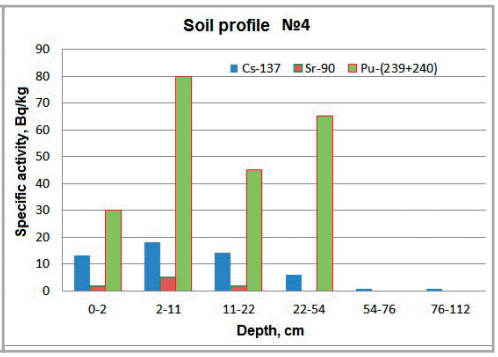

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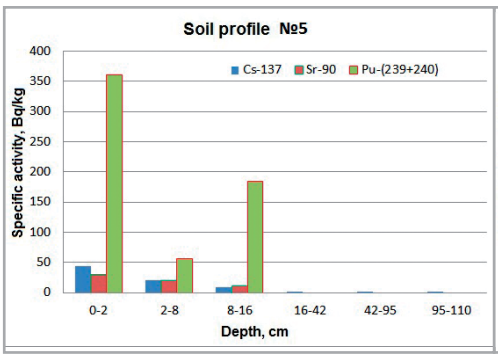

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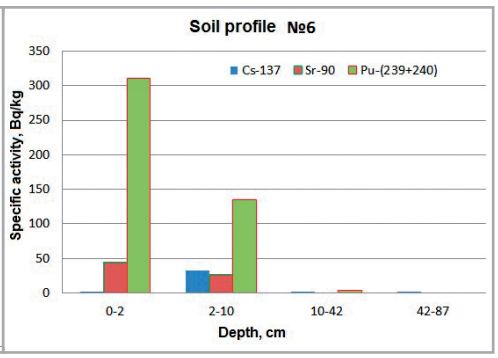

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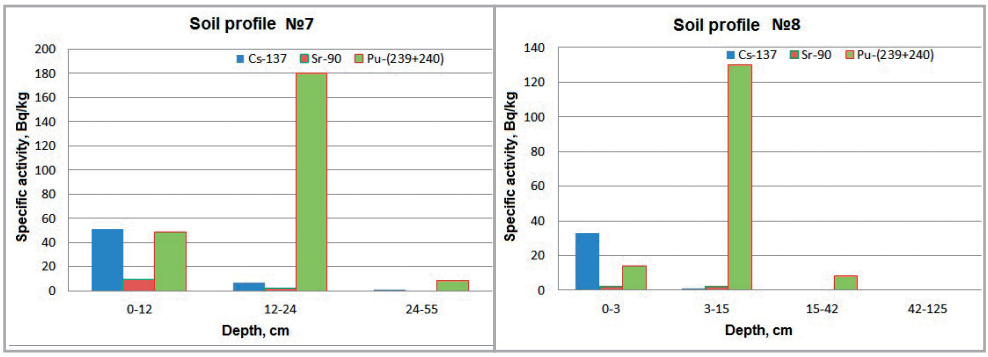
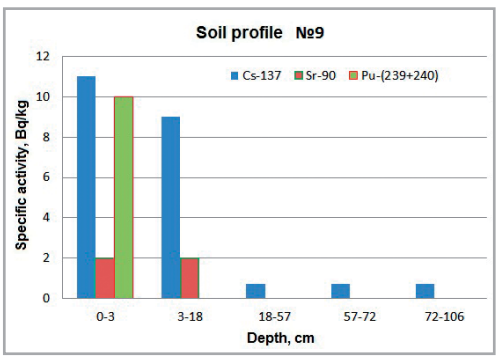


g) h)



i)

Figure 7. Radionuclide distribution in soil horizons

As the table and graphs show, the maximum concentration of ^{137}Cs is observed in the surface soil horizons (0-2, 0-3 cm) and in section 6 it is about 110 Bq/kg. This section is placed near the axis of radioactive fallout trace from the first nuclear tests on meadow soils, and on the depression slope in the centre of which there is a swamp. Lower values of this radionuclide (60 and 50 Bq/kg) are observed in the upper horizon of nearby sections 5 and 7, respectively. With the depth, the values of ^{137}Cs drop down several times and at a depth of 15-20 cm they are at the detection limit (<0.7). Such distribution of ^{137}Cs is noted regardless of the soil texture.

The maximum values of ^{90}Sr reach 44 Bq/kg in the surface horizons of section 6 located on the depression slope, where the excessive values of ^{137}Cs are observed. The second largest value was observed in the surface horizon of section 1 located in the Irtysh River valley. According to the data on two sections, the values in the second horizon go down by 30-35% regardless of the soil texture. However, due to the lack of data on all horizons, it is impossible to give more detailed description of ^{90}Sr radionuclide penetration in the soil profile.

The maximum fallout of $^{239+240}$Pu from the radioactive cloud within the surveyed area occurred in the depression slope, and the maximum concentration is observed in the

surface horizons of sections 5 and 6, which is 360 and 310 Bq/kg, respectively. These sections are located near the axis of the radioactive fallout trace from the first nuclear test. It should be noted that in case of light soil texture represented by sandy clay in section 6, intensive migration of this radionuclide occurred in the underlying layer. So, the concentration of $^{239+240}$Pu in the horizon second from the surface (2-10 cm) is approximately 45% of the content in the 0-2 cm layer. Whereas in section 5, the profile is formed by light loams and the amount of the material, which migrates from the surface into the second layer, is only 16-17%. The movement of maximum concentration of this radionuclide into the second and third layers due to light soil texture is observed in section 4, where sandy pulverescent deposits prevail in the soil profile. This is not a single case when values noted in the underlying horizon are higher than in the top horizon, which is possible with the light texture of soils represented by powdery sand or sandy clay soil due to scattered ground. The depth of $^{239+240}$Pu radionuclide penetration into the soil profile usually reaches 30 cm, and in rare cases – 50 cm. The man-caused interference is equally important: for example, in section 2 the field was ploughed and clover was planted, and in section 8 the field was ploughed to plant pines. These factors, most probably, disturbed the natural texture of soil and moved the layers of radioactive contaminated soil. It is quite possible that in the area of sections 4 and 7, which are now located in the open area, the works were also performed connected with the movement of top soil layer, which is evidenced by the characteristic distribution of radionuclides.

Therefore, the maximum contamination with man-made radionuclides is observed near the axis of the radioactive fallout trace from the first nuclear test. Distribution of ^{137}Cs and ^{90}Sr radionuclides in the soil horizon is not connected with the types and texture of soil, unlike $^{239+240}$Pu radionuclides where such dependency is noted. In order to study the penetration of man-made radionuclides into the depth, the soil layers sampled at regular space of 5 cm shall be studied.

Accumulation factor of ^{137}Cs by the plants is highly variable ranging from 0.01 to 7.00 (Table 7). Apparently, the accumulation of this radionuclide by the plants depends on both the physicochemical properties of soil, primarily mechanical composition and amount of organic matter, and the biological features of the plants caught in the test sample. However, such high concentrations of ^{137}Cs in the vegetation raises doubts, therefore these data needs to be verified in future.

Lack of measurements of ^{90}Sr and $^{239+240}$Pu concentrations in vegetation samples does not allow calculating their accumulation factor.

Table 7.

Accumulation factors (Af) of arificial radionuclides in the over ground part of composite plant samples collected on the surveyed areas

Place of sampling	Specific activity ^{137}Cs, Bq/kg		Kn
	Soil	Plants	
River terrace, wasteland, section 1	12	35	2,9
Terrace slope, deposit, section 2	41	0,8	0,01
Clearing in forest, section 3	39	8,1	0,20
Clearing in forest, section 4	20	25	1,2
Clearing in forest, slope, section 5	60	27	0,4
Clearing in forest, slope, section 6	112	12,1	0,10

Place of sampling	Specific activity ^{137}Cs, Bq/kg		Kn
	Soil	Plants	
Clearing in forest, slope, swamp 7	51	79	1,6
Clear-bold forest, forest meadow, section 8	33	43	1,3
Clearing in forest, hay field, section 9	11	77	7,0

STUDY OF INHABITED LOCATIONS

After the termination of nuclear tests and closure of Semipalatinsk Test Site (STS) on August 29, 1991, the question of clarifying the extent of radioactive contamination of environment was raised, as well as the question of clarifying the damage caused by the test field operation to the health of people in the adjacent regions.

Cheremushki, Mostik and Dolon villages are located on the right bank of the Irtysh River at a distance of 90, 96 and 108 km respectively, and Bodene village is located on the left bank at a distance of 94 km from the centre of Testing Area of the former STS. The most significant radioactive contamination of this region occurred after the first nuclear test (08.29.1949). The axis of trace goes at a distance of 1.5 km from the northern suburb of Dolon village where more than a thousand people were residing in that period (Figures 1 and 5).

Specialists of Radium Institute (St. Petersburg) conducted field radiological surveys in 1991-1992 as part of *Region 1 Comprehensive Program* in Mostik and Dolon villages [3, 8]. γ-radiation doses were measured in the places of soil and vegetation sampling. It was established that the average dose in Dolon village did not exceed 16 mcR/h, and in Mostik village it was in the range of 12-18 mcR/h with an average value of 14 mcR/h.

The analysis results of soil samples that were collected throughout Dolon evidenced that the contamination of the village area was spotty. Relatively high concentration of ^{137}Cs and $^{239+240}$Pu was observed in soil samples taken in the northern part of the village, which was located near the axis of the trace formed after the first nuclear explosion.

The density of surface contamination with ^{137}Cs in Mostik area did not exceed the level of global fallouts and was about 50 m Ci/km^2. It was established that ^{137}Cs was contained predominantly in the upper 10 cm soil layer and its concentration in vegetation is approximately 0.1 Bq/g of ash which is significantly less than the concentration of such natural radionuclide as ^{40}K.

Findings of the survey performed in early 90's confirmed that the radioactive trace from the first nuclear test was located between Dolon and Mostik villages with the distance between them of 12 km.

The most biologically significant radionuclide $^{239+240}$Pu is contained in the soil of villages in two main aggregate states. The first main state – soil particles of fire-polished ground up to 100 microns, from which plutonium cannot be recovered by weak chlorohydric acid as the laboratory tests showed. The second state – finely-divided state that enables the transfer of plutonium from soil into weak acid solutions, in other words it is the mobile migration-capable plutonium condition.

Following the results of laboratory analysis of soil samples it was established that only 1-3 % of plutonium is in the mobile readily soluble form and is bioavailable [3].

Sample analysis of meat and bones of live-stock animals, milk, potable and natural water from Dolon village showed that the concentration of radioactive substances were 10-100 times lower than the maximum allowed levels (MAL) accepted at the time of the study. Concentration of α- and β-emitting radionuclides in the air of Dolon village is 100-1000 times less than allowed levels for residential areas. Analysis of filters for the concentration of $^{239+240}$Pu showed that its concentration is 3-15 times lower than the allowed levels [9].

According to the studies conducted in the 90's, the radiation situation in Dolon and Mostik villages is normal. There is no data on radioecological studies performed in Cheremushki and Bodene villages.

In 2004, specialists of IRSE conducted the radiological survey of Dolon, Mostik, Cheremushki and Bodene. The survey results were presented in the report [10].

Radiological survey of Dolon village

In Dolon, the foot gamma survey was carried out along the streets of the village with the fixed EDR measurements in the points spaced at 20 meters, and additional measurement at the entrance to each farmstead. More than 1200 EDR measurements were taken. Radiation parameters are in the range from 0.09 to 0.12 mSv/h. No any anomalies or radioactive contaminated areas were found based on the data received. At the same time, foot topographic survey of main streets and buildings was carried out with the use of GPS-receiver in the village, and the contour of settlement was made. The results of foot gamma survey are presented in Figure 8.

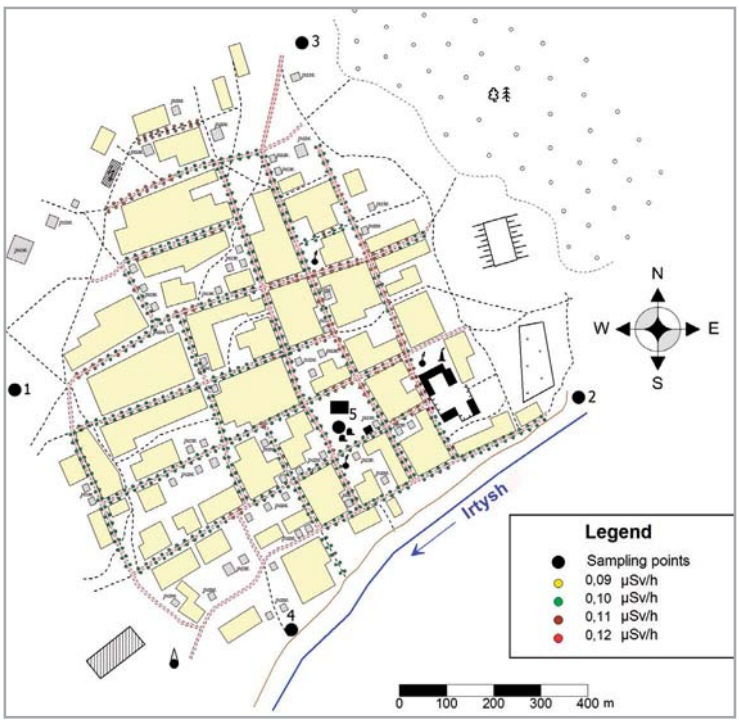


Figure 8. Results of pedestrian gamma-survey of Dolon

To assess radionuclide contamination of the Dolon village area, 5 soil samples were collected (4 soil samples in the cardinal directions at 100-meter distance from the edge of the village and one sample from the centre). Soil sampling was conducted by the "envelope" method with the 10 m side at a depth of 10 cm (the sampling area is 300 cm^2). In the eastern suburb of the village at the place of soil sampling, a vegetation sample of 2 kg was taken from the area of 2 m^2.In each survey point, the equivalent dose of γ-radiation was measured on the surface of soil at a height of 1 m, and of the flow density of α and β particles. The equivalent doses of γ-radiation on the soil surface and at the 1 m height is in the range from 0.11 to 0.13 mSv/h and from 0.09 to 0.12 mSv/h respectively. The flow density of α and β particles does not exceed 1 and 10 parts/(min * cm^2) respectively. These figures are at the background values.

In the backyard (garden) located at Ivana Dits St., house No.17, one soil sample was collected. From the same area, vegetable samples were taken for laboratory analysis to determine radionuclide composition (potatoes, carrots, tomatoes). Also, one milk sample and one meat sample (meat was purchased in the grocery shop) were collected. Meat and milk was from the animals that were grazed in the suburbs of the village.6 measurements of the equivalent equilibrium volume activity (EEVA) of radon and thoron daughter product were taken in the premises of residential and public buildings. The results of these measurements (Table 8) showed that radon EEVA did not exceed the allowed average annual value of 200 Bk/m^3. The maximum values of radon EEVA of 90 Bq/m^3 were registered in house No.17 on Ivana Dits St. Concentration of thoron daughter products in the surveyed areas did not exceed the detection threshold of 8 Bq/m^3.

Table 8.

Results of EEVA measurements in Dolon village

Sampling place	$EEVA_{Rn}$ (radon), Bq/m^3	Allowed value of $EEVA_{Rn}$ + 4,6*$EEVA_{Tn}$
School (biology class room)	23	200 Bq/m^3
School (school hall)	90	
Ivana Dits St., house No.28	30	
Ivana Dits St., house No.17	90	
Akimat (office)	5	
In the open area next to Akimat	17	

Radiological survey of Mostik village

In Mostik village, foot gamma-survey was conducted in the same manner as in Dolon village. More than 600 measurements of EDR were taken. The values are in the range from 0.09 to 0.12 mSv/h. No any anomalies or radioactive contaminated areas were identified based on the data received. Foot topography survey of the main streets and buildings was conducted, the contour of settlement and the layout of the village were made. The results of pedestrian survey are presented in Figure 9.

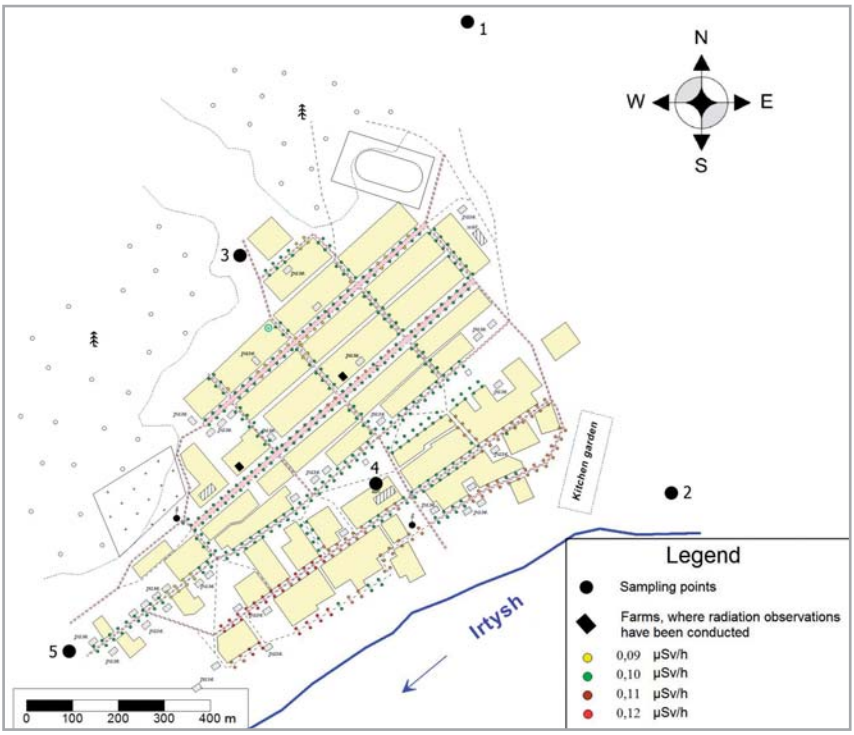


Figure 9. Results of foot gamma-survey in Mostik village

To assess radionuclide contamination of Mostik village, 5 soil samples were collected in the same manner as during the survey of Dolon. In eastern suburbs of the village at the place of soil sampling, the vegetation soil of 2 kg was taken from the area of 8 m^2. The equivalent dose of γ-radiation on the soil surface and at the 1 m height is in the range from 0.10 to 0.12 mSv/h and from 0.09 to 0.11 mSv /h, respectively. The flow density of α and β particles does not exceed 1 and 10 parts/(min * cm2) respectively. These values are at the level of background values.6 measurements of EEVA of radon and thoron daughter products were taken in the premises of residential and public buildings. The results of these measurements (Table 9) showed that radon EEVA did not exceed the allowed average annual value of 200 Bq/m^3. The maximum value of radon EEVA of 16 Bq/m^3 was registered in household No. 26 on Lenina St. Concentration of thoron daughter products in the surveyed premises did not exceed the detection threshold of 8 Bq/m^3.

Table 9.

Result of radon EEVA measurements in Mostik village

Sampling place	$EEVA_{Rn}$ (radon), Bq/m^3	Allowed value of $EEVA_{Rn}$ + 4,6*$EEVA_{Tn}$
School (teachers' room)	12	200 Bq/m^3
Lenina St., house No.26	16	
Lenina St., house No.6	14	
Building of Dolon Branch of State Forest Natural Reserves (SFNR)	14	
In the open area next to the building of Dolon Branch of SFNR	9	

In the course of the survey, radiation parameters were measured in residential premises, as well in the backyard. Samples of milk, agricultural products (potatoes, cabbage, tomatoes, carrots) that were grown in two backyards were taken, and soil samples were collected from these sites by the "envelope" method.

In Cheremushki and Bodene townships, the pedestrian gamma survey was conducted along the streets with fixed measurements in points every 20 m. At the entrance to each courtyard, additional EDR measurements were taken. The profiles of the survey went beyond the settlements for 100 meters. No any anomalies or radioactive contaminated areas were identified based on the data received. The EDR values vary within the following limits: in Cheremushki – 0.10-0.14mSv /h; in Bodene – 0,10-0,13 mSv /h. To assess the radionuclide contamination of the Cheremushki and Bodene residential areas, 5 soil samples were taken in the same manner as during the survey of Dolon village.Total of 25 soil samples, 13 food samples and 2 vegetation samples were collected in Dolon, Mostik, Cheremushki and Bodene.

Concentration of radionuclides in soil25 soil samples were analysed by gamma-spectrometry and radiochemical method. The results of laboratory analyses are shown in Table 10.

Table 10.

Specific activity of radionuclides in soil samples collected in the residential areas

No.	Sampling place	Sampling point	Concentration of radionuclides, Bq/kg					
			^{40}K	^{232}Th	^{226}Ra	^{137}Cs	^{90}Sr	$^{239+240}$Pu
1	Dolon	garden	810±90	30±6	15±5	12±4	4.6±2.7	6±3
2	Dolon, western suburb	point 1	810±70	36±4	28±5	16±2	5.8±4.0	17±4
3	Dolon, eastern suburb	point 2	790±80	32±4	36±5	11±3	2.6±1.4	24±6
4	Dolon, northern suburb a	point 3	730±60	25±3	16±3	16±2	<2	16±3
5	Dolon, southern suburb a	point 4	790±70	31±4	32±5	9±2	<2	5.8±1.9
6	Dolon, centre	point 5	760±70	32±4	24±5	5±2	<2	2.6±0.8
7	Mostik, Lenina St. 6	garden	800±70	13±2	36±5	21±3	7±3	3.1±1.1
8	Mostik, Lenina St. 26	garden	750±70	21±4	13±4	20±3	3.8±1.7	6±3
9	Mostik, northern suburb	point 1	770±90	23±2	20±3	8±2	3.8±1.6	3.6±1.9
10	Mostik, eastern suburb	point 2	620±70	44±5	33±5	17±3	3.9±1.7	3.4±1.8
11	Mostik, western suburb	point 3	730±60	20±3	18±3	6±2	3.3±1.5	<1
12	Mostik, centre	point 4	770±60	19±3	14±3	4±1	4.0±2.3	1.2±0.5
13	Mostik, southern suburb	point 5	770±60	21±3	19±3	8±1	2.0±1.6	<1
14	Cheremushki	garden	630±90	35±6	23±6	7±3	24.6±7.6	1.8±1.3
15	Cheremushki, northern suburb	point 1	940±80	41±4	29±5	14±2	5.7±2.1	<1
16	Cheremushki, eastern suburb	point 2	700±70	41±5	35±5	13±3	5.4±2.4	10±3
17	Cheremushki, southern suburb	point 3	820±70	30±4	20±4	14±2	5±2	-
18	Cheremushki, centre	point 4	720±70	32±3	22±4	12±2	3.3±2.1	-
19	Cheremushki, western suburb	point 5	690±70	50±5	27±5	12±2	<2	-
20	Bodene, northern suburb	point 1	710±60	32±4	23±4	20±3	6.4±2.4	10±3
21	Bodene, southern suburb	point 2	760±50	21±3	18±3	17±2	<2	-
22	Bodene, western suburb	point 3	780±50	23±3	18±3	8±2	9.8±4.9	3.0±0.9
23	Bodene, eastern suburb	point 4	780±50	23±3	18±3	8±2	<2	5.6±1.7
24	Bodene, centre	point 5	810±60	27±3	23±4	20±2	1.8±1.8	3.8±1.2
25	Bodene	garden	870±100	48±12	25±11	12±4	3.8±2.6	4.9±1.5
Notes : "-"no analysis was performed								

Following the analyses, it was established that the values of natural radionuclides are at the level of average concentration of these elements in the soil of Kazakhstan, which is conditioned by the soil types and geological structure of the earth's crust in this area.

The data in Table 10 show that concentration of the artificial radionuclide ^{137}Cs in soil in the surveyed points varies from 4 to 21 Bq/kg, which is at the level of background global fallouts that is 65 mCi/km^2 (15 Bq/kg for the depth of 10 cm) [6]. The maximum concentration of ^{137}Cs of 21 Bq/kg was discovered in the sample taken in Mostik village in the backyard located at Lenina St., house No.6 (garden). Specific activity of man-made radionuclides ^{90}Sr and $^{239+240}$Pu in soil is in the range from <2 to 24.6 Bq/kg and from <1 to 24 Bq/kg respectively. Concentration of ^{90}Sr in all soil samples is below the level of background global fallouts, that is 39 mCi/km^2 (9 Bq/kg) [6], except for one sample collected in the garden in Cheremushki village. Following the laboratory studies, it was established that concentration of $^{239+240}$Pu radionuclide practically in all samples exceeds the level of background global fallouts accepted for this radionuclide at 0.5-2.67 Bq/kg [11], that is 9 times exceeding. Maximum concentrations of $^{239+240}$Pu in soil were discovered in the eastern, northern, and western sub-

urbs of Dolon village due to the radioactive fallouts from the first nuclear explosion cloud. It should be noted that higher concentrations of ^{137}Cs and ^{90}Sr, as compared to other surveyed points, were discovered in the soil of gardens. Perhaps this is because the organic fertilizer (cow manure) is added to the garden soil every year, and the cows always graze in the areas adjacent to the townships, including the areas of radioactive fallout trace.

Radionuclides concentration in food and vegetation

13 samples of food samples (meat, milk, potatoes, tomatoes, cabbage and carrots) were analysed by gamma-spectrometry and radiochemical method, and these samples were collected on the backyards in Mostik and Dolon villages, and 2 vegetation samples taken from their suburbs were also analysed. The results of laboratory analyses are shown in Table 11.

Table 11

Specific activity of radionuclides in food and vegetation samples

No.	Samples	Place of sampling	Radionuclide concentration, Bq/kg				
			^{137}Cs	Allowed levels	^{90}Sr	Allowed levels	$^{239+240}$Pu
1	potato	Dolon, I.Dits St.17	<0.2	120	<0.2	40	<0.5
2	potato	Mostik, Lenina St. 6	1.6±1.3		0.7±0.4		<0.1
3	potato	Mostik, Lenina St. 26	4±2		0.8±0.8		<0.1
4	carrot	Dolon, I.Dits St.17	<0.2	120	0.4±0.4	40	<0.5
5	carrot	Mostik, Lenina St. 26	2.7±1.6		0.9±0.9		<1
6	tomato	Dolon, I.Dits St.17	<0.2	40	5.5±3.1	30	<1
7	tomato	Mostik, Lenina St. 6	3.2±1.7		5.3±4		<0.8
8	cabbage	Mostik, Lenina St. 6	<0.2	40	4.4±2.3	30	<0.5
9	cabbage	Mostik, Lenina St. 26	<0.2		10±9		<0.8
10	milk	Dolon, I.Dits St.17	2.2±1.3	100	0.6±0.6	25	<0.2
11	milk	Mostik, Lenina St. 26	1.7±1.0		<0.2		<0.2
12	meat	Dolon	<0.2	200	2.2±0.6	50	<0.2
13	meat	Mostik	<0.2		2.9±1.2		<0.2
14	plants	Mostik, point 2	<0.3	74	0.7±0.3	111	<0.1
15	plants	Dolon, point 2	0.5±0.1		0.2±0.2		<0.1

As it is evident from the table, the specific activity of ^{137}Cs and ^{90}Sr radionuclides in food and vegetation samples does not exceed 3.2 and 10.5 Bq/kg respectively, which, according to the hygienic standards [12], is below the allowed concentration of these radionuclides in food. Acceptable concentrations of these radionuclides in food are shown in Table 11.

In the vegetation, the maximum concentration of ^{137}Cs was registered in the sample taken in the suburb of Dolon village at the level of 0.5 Bq/kg, which does not exceed the allowed level under the regulations of the Ministry of Agriculture of the Republic of Kazakhstan (74 Bq/kg). [13]

Maximum concentration of ^{90}Sr in vegetation was registered at the same place at the level of 0.7 Bq/kg, which is well below the allowed level (111 Bq/kg). [13]

Concentration of $^{239+240}$Pu in vegetation does not exceed the detection level of equipment. Contamination of vegetation with transuranic radionuclides is not regulated in Kazakhstan.

The data received from radiological survey in 2004 is well consistent with the results of studies performed by specialists of Radium Institute (St. Petersburg) in 1991-1992 as part of Region-1 Comprehensive Program.

Based on the results of studies performed, the following findings were made, which served as the starting point for further studies:

1. The data obtained during the hydrolithochemical survey can be used only for the assessment of radionuclide concentration in a certain surveyed area, and one should refrain from the use of the data interpreted based on the combination of radioactive contaminated areas by means of combining micro basins.
2. The data obtained on ^{137}Cs concentration in soils of the surveyed area indicates that the radionuclide distribution is spotty, which is, apparently, connected with its fallout from the radioactive cloud formed as a result of the first nuclear test. The area of the detected site with excessive concentration of ^{137}Cs covers more than 4 km^2. It might become a starting point for determination of space and positioning of grid to sample natural component in order to determine other radioactive fallout traces from the ground nuclear tests conducted on the STS.To identify the nuclear tests that could have caused the contamination of Irtysh forests, and to identify radioactive fallout traces, one should collect all available information.
3. Maximum concentrations of ^{137}Cs radionuclides are in the plant litter and several times higher in the soil. In the litter, the maximum concentration of ^{137}Cs is in most cases found in sandy component if compared to the plant component. Distribution of ^{137}Cs and ^{90}Sr radionuclides in soil horizons is not related to the soil types and texture, unlike the revealed distribution of $^{239+240}$Pu radionuclide where such dependency is observed. It should be noted that in the open areas of the surveyed site, excessive radionuclide concentrations are observed in deeper soil layers due to the anthropogenic interference (ploughing).
4. In the course of gamma-spectrometric analysis of single soil samples and litter, ^{241}Am radionuclide was detected, which might evidence the presence of plutonium isotopes. However, no ^{241}Am radionuclide was detected in soil samples where hundreds of Bq/kg of $^{239+240}$ Pu were registered. Studies of radionuclide concentrations in herbaceous and woody vegetation made it possible to determine the accumulation factors that differ by several orders and range from hundredths to units.
5. At present, the radiation situation in residential areas is normal. Concentration of radionuclides in the natural environment does not exceed the allowed levels. In general, the data that we obtained is well consistent with the results of works performed by international researchers.

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ЕРТІС ЖАҒАЛАУЫНЫҢ ҚАРАҒАЙЛЫ ОРМАН АУМАҒЫНДАҒЫ РАДИАЦИЯЛЫҚ АХУАЛ

Стрильчук Ю.Г., Осинцев В.С., Магашева Р.Ю.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Семей сынақ полигонында (ССП) көптеген жылдар бойы ядролық қаруды сынауға жасалған сынақтардың салдарынан тек қана полигон аумағы емес, сонымен қатар оған жақын жатқан аумақтар да радиоактивті ластану әсеріне ұшырады. Осындай аумақтардың біріне ССП солтүстік-шығыс бағытта орналасқан Ертіс жағалауы бойындағы қарағайлы орман тізбегінің қаулап өскен бөлігі жатады.

Ертіс жағалауының бойындағы қарағайлы орман Ертіс өз. оң жақ жағалауында Қазақстанның екі облысы – Шығыс-Қазақстан мен Павлодар облыстарының аумақтарында орналасқан. Қарағайлы орманның жалпы аумағы 870,5 мың га құрайды. Орманқұраушы ағаш түрі – қарапайым қарағай (Pinussilvestris). Қарағайлы орман көне заманғы болып табылады және үлкен экологиялық, әлеуметтік-экономикалық маңызға ие.

Орман экожүйелерінің радиоактивті ластануының негізгі радиологиялық зардабына радионуклидтердің орман өнімдерінде жинақталуы және оларды одан әрі пайдалануын шектеу, орман шаруашылығына қамтылған қызметкерлердің және тұрғындардың сыртқы және ішкі сәулеленуі жатады. Қорғану шаралары белсенді түрде қолданылуы мүмкін ауыл шаруашылығы жерлеріне қарағанда, орман құрауыштарындағы радионуклидтердің құрамының негізінен өзгерісі табиғи факторлардың есебінен болады. Олардың ұзақ уақыт бойы өздігінен тарзартылуы себепті, орман экожүйелері ұзаққа дейін тұрғындар үшін де, орман шаруашылығы жұмыскерлері үшін де радиациялық қатердің көзі болып табылады.

Кілт сөздер: қарағайлы орман, алғашқы ядролық сынақ, техногенді радионуклидтер, топырақ бейіні, радиациялық ахуал.

РАДИАЦИОННАЯ ОБСТАНОВКА НА ТЕРРИТОРИИ СОСНОВЫХ БОРОВ ПРИИРТЫШЬЯ

Стрильчук Ю.Г., Осинцев В.С., Магашева Р.Ю.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

Многолетние испытания ядерного оружия на Семипалатинском испытательном полигоне (СИП) привели к радиоактивному загрязнению не только части территории самого полигона, но и прилегающих к нему территорий. Одной из таких территорий является полоса произрастания ленточного бора Прииртышья, расположенная в северо-восточном направлении от СИП.

Ленточный бор Прииртышья расположен на правобережье р. Иртыш на территории двух областей Казахстана – Восточно-Казахстанской и Павлодарской. Общая площадь ленточного бора составляет 870,5 тыс. га. Лесообразующая порода – сосна обыкновенная (Pinussilvestris). Ленточный бор является реликтовым и имеет большое экологическое и социально-экономическое значение.

Основным радиологическим последствием радиоактивного загрязнения лесных экосистем является накопление радионуклидов в лесной продукции, ограничивающее ее дальнейшее использование, внутреннее и внешнее облучение населения и персонала, занятого в лесном хозяйстве. В отличие от сельскохозяйственных угодий, на которых могут активно применяться защитные мероприятия, изменение содержания радионуклидов в компонентах леса происходит главным образом за счет естественных факторов. Вследствие длительного времени их самоочищения, лесные экосистемы надолго становятся источником радиационного риска для населения и работников лесного хозяйства.

Ключевые слова: ленточный бор, первое ядерное испытание, техногенные радионуклиды, почвенный профиль, радиационная обстановка.

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RADIOACTIVE CONTAMINATION OF THE SHAGAN RIVER WATERS (2011 RESULTS)

Aidarkhanov A.O., Lukashenko S.N., Genova S.V., Lyakhova O.N., Aidarkhanova A.K.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

The paper reports on the studies of character and levels of contamination in Shagan River. It has been revealed that the significant concentrations of ^{90}Sr in Shagan River waters are not directly related to the "Atomic Lake". Tritium was detected in the water all over Shagan River from "Atomic Lake" to a confluence with Irtysh River, where its specific activity was 50 Bq/kg. Maximal tritium in channel waters occurred in spring and was 200 kBq/kg.

Keywords: Shagan River, radioactive contamination, tritium, "Atomic Lake."

INTRODUCTION

Systematic investigations of tritium concentrations aimed at studying of the nature and source of radioactive contamination of the Shagan River waters started in 2006, when anomaly high tritium concentrations were registered in the section of the Shagan River. In 2009 maximal tritium concentrations as high as 680,000 Bq/kg were registered at a distance of 4.4 km from the "Atomic Lake", and the values not exceeding 20 Bq/kg were detected at the confluence of the Shagan and Irtysh rivers. As a result of our investigations of the Shagan waters, significant concentrations of ^{90}Sr as high as 0.7 Bq/kg were registered, however, no presence of ^{137}Cs и $^{239+240}$Pu was detected [1].

The most probable sources of radioactive contamination of the Shagan River are the inflow of ground waters from the testing ground Balapan, where nuclear tests were made in the boreholes, and the inflow of surface waters from the water reservoir formed as a result of the explosion in the borehole № 1004 ("Atomic Lake") [2].

The objective of the present work is to study the formation mechanisms for the radioactive contamination in Shagan River. To solve this problem it is necessary:

- to detect potential sources of ^{90}Sr inflow into the Shagan River;
- to determine specific features of tritium distribution downstream the Shagan River from the Atomic Lake to its flowing into the Irtysh River.

1. EXPERIMENTAL PART

The scope of research in 2011 included field works, where water samples were taken, and laboratory analyses of samples, which determined specific activity of artificial radionuclides.

1.1. Field works

Sampling for determination of tritium specific activity

According to ST RK GOST P 51592-2003 the volume of samples taken for determination of tritium specific activity was 0.2 liters [3].

Sampling for determination of ^{90}Sr, ^{137}Cs, $^{239+240}Pu$ specific activity

The volume of samples taken for determination of specific activity of ^{90}Sr, ^{137}Cs and $^{239+240}Pu$ was 10 liters. The samples used to determine activities of ^{90}Sr, ^{137}Cs and $^{239+240}Pu$ were filtered immediately after sampling and conserved by nitric acid in proportion of 3ml/1l of the sample. Samples were delivered to the laboratory either directly after sampling or within 48 hours.

1.2 Laboratory analyses

Determination of tritium concentration

According to ISO9698/1989 ^{3}H concentration was determined by the methods of liquid scintillation spectrometry on β-spectrometer TRI-CARB2900 TR [4].

Determination of ^{90}Sr, ^{137}Cs and $^{239+240}Pu$ concentrations

^{90}Sr, ^{137}Cs and $^{239+240}Pu$ concentrations were determined by spectrometric methods after radiochemical extraction from preliminary concentrated sediments of salts (co-precipitators) with radionuclides. ^{90}Sr was precipitated by calcium carbonate, ^{137}Cs – by copper ferrocyanide, $^{239+240}Pu$ – by iron hydroxide [5]. Specific activity of ^{137}Cs was measured on γ-spectrometer ORTECGMX 20P4. Specific activity of ^{90}Sr was determined according to the method presented in [4] using beta-spectrometer TRI-CARB2900 TR. Alpha-spectrometric measurements of specific activity of $^{239+240}Pu$ were made on Canberra spectrometer.

2. RESULTS AND DISCUSSION

2.1. Identification of possible sources of ^{90}Sr entry into the Shagan River

^{90}Sr can entry surface waters of the Shagan River:

- with the water from the "Atomic lake";
- as a result of washing-off from the daylight surface contaminated by the explosion in the borehole № 1004; – with washing-outs from bottom sediments;
- inflow of contaminated ground waters from the test ground "Balapan". An assumption that ^{90}Sr can entry with waters from the "Atomic lake" is based on the results of investigations of the radionuclide composition of the "Atomic lake" waters done in the previous years (Table 1).

Table 1

Results of laboratory analyses in the previous years

№	Year of investigations	Average value of ^{90}Sr specific activity, Bq/kg	Average value of ^{3}H specific activity, Bq/kg	Average value of ^{137}Cs specific activity, Bq/kg	Average value of ^{239,240}Pu specific activity, Bq/kg
1	2000	1.6	-	2	-
2	2001	9.4	-	0.6	4.6
3	2003	5.7	10 000	1	0.032

As it is seen from the data, the "Atomic lake" waters have rather high concentrations of ^{90}Sr. Hence, waters of the crater are the most probable source of strontium contamination of the Shagan River.

In 2011 works on identification of the source of contamination started from studying surface waters in the vicinity of the "Atomic Lake". In order to determine ^{90}Sr concentrations samples were taken in 6 points: point 1 – the place where the Shagan River flows into the external water reservoir, point 2 – a connecting channel, point 3 – the "Atomic Lake" crater, point 4 – the external water reservoir, point 5 – outflow of the Shagan River from the "Atomic Lake" (dam), point 6 – the place where the Aschicy River flows into the external water reservoir. In order to reduce the influence of melt and flood waters on the concentration of artificial radionuclides sampling was made in August. In the samples concentrations of ^{3}H, ^{137}Cs and $^{239+240}$Pu were determined. The scheme of water sampling is shown in the figure (Figure 1).

The results of investigations are presented in the table (Table 2).

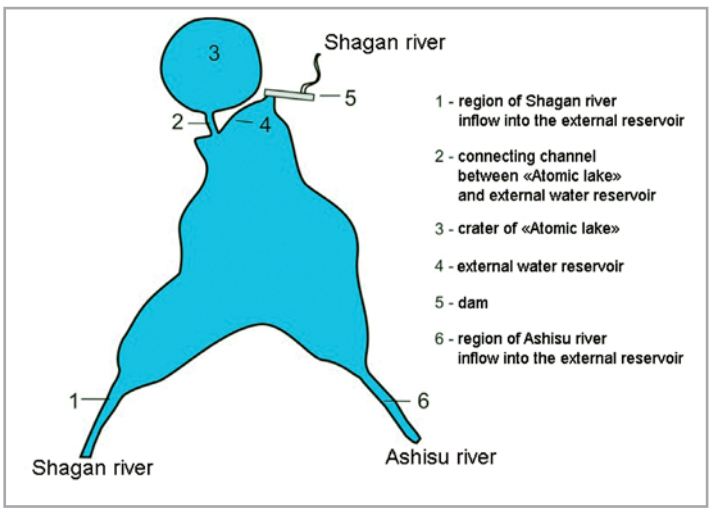

Figure 1. Location of sampling points on the "Atomic Lake".

Table 2.

Results of laboratory analyses

№	Sampling place	Sampling point	^{90}Sr, Bq/kg	^{3}H, Bq/kg	^{137}Cs, Bq/kg	$^{239+240}$Pu, Bq/kg
1	The mouth of the Shagan River	T-1	<0.006	20 ± 2	< 0.03	<0.001
2	Connecting channel	T-2	<0.005	60 ± 6	< 0.01	<0.001
3	"Atomic Lake" crater	T-3	<0.004	60 ± 6	< 0.01	<0.001
4	External water reservoir	T-4	<0.005	40 ± 4	< 0.03	<0.001
5	Dam	T-5	<0.005	35 ± 3	< 0.01	<0.001
6	The mouth of the Aschisy River	T-6	<0.004	20 ± 2	< 0.02	<0.002

The results of investigations show that the ^{90}Sr specific activity is lower than the minimal detected activity of used devices (0.004 Bq/kg) It should be noted that the observations in 2000-2003 registered significant quantities of strontium (up to 10 Bq/kg) in the "Atomic Lake" waters. Considerable variations in the ^{90}Sr concentrations in water can be caused by the hydrological regime in the area, i.e. variations in the water level, discharge, composition and concentration of dissolved substances. Thus, the average value of water salinity in water samples in 2001 was 9,400 mg/dm^3, whereas in 2011 it was 5,100 mg/dm^3. Concentrations of ^{3}H, ^{137}Cs and $^{239+240}$Pu in water also varied in a wide range.

In the samples taken in monitoring points in August concentrations of artificial radionuclides ^{137}Cs and ^{90}Sr were determined. The results of investigations are presented in the table (Table 3).

Table 3.

Results of laboratory analyses

№	Sampling point	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg
1	M-24 (4 km)	< 0.01	0.1 ± 0.01
2	M-26 (5 km)	< 0.01	0.2 ± 0.01
3	M-31/1 (6 km)	< 0.03	0.1 ±0.01
4	38 km	< 0.02	<0.01
5	110 km	< 0.02	<0.01

As it is seen from the data the concentration of artificial radionuclide ^{137}Cs was lower than the minimal detected activity. However, at a distance of 6 km from the "Atomic Lake" the presence of artificial radionuclide ^{90}Sr was registered in water. This fact shows that its source is not connected with the inflow of contaminated surface waters. It can be explained either by washing-off of the radionuclide from bottom sediments, shore soils or by inflow of contaminated ground waters.

Therefore, it is still impossible to give an unambiguous answer to the question about the influence of the "Atomic Lake" on the ^{90}Sr contamination in the Shagan River. It is necessary to study the dynamics of variations in the concentration of artificial radionuclides in the "Atomic Lake" waters during a year period.

The other probable sources of contamination such as washing-off from the daylight surface contaminated by the explosion in the borehole № 1004, washing-outs from bottom

sediments and inflow of contaminated ground waters from the test ground "Balapan" have not been studied either.

2.2 Determination of specific features of tritium distribution in the Shagan River downstream from the "Atomic Lake" to the inflow in the Irtysh River

The investigations in 2010 were the first that determined qualitative values of ^{3}H concentrations along the river to the place of its flowing into the Irtysh River where the tritium specific activity was 400 Bq/kg. In order to confirm the results similar measurements of the ^{3}H distribution along the Shagan River were made in 2011. The structure of ^{3}H distribution along the riverbed in 2010-2011 is shown in the Figure 2.

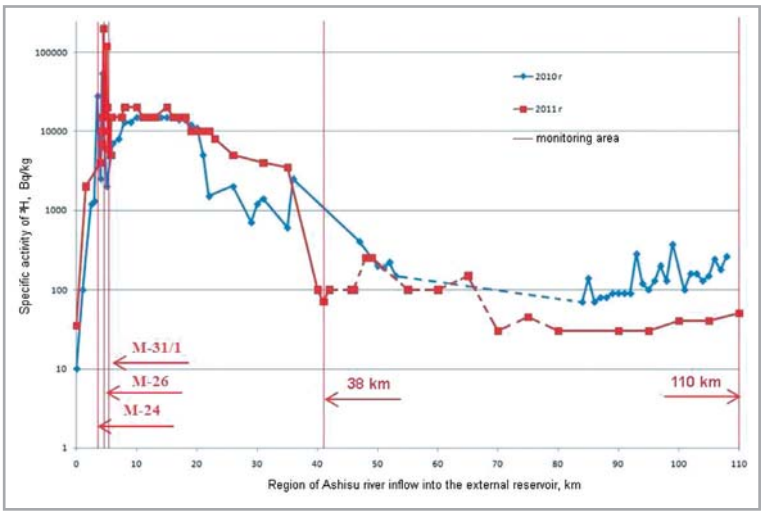

Figure 2. Distribution of tritium specific activity downstream the Shagan riverbed in 2010-2011.

The main result of the 2011 investigations was confirmation of the fact of tritium inflow into the Irtysh River with the waters of the Shagan River. A higher tritium specific activity as compared with 2010 was registered in the 4-10 km river section. Moreover, in 2011 scientists took water samples in the section 53-84 km, which was not studied in 2010 because of the absence of water (Figure 2).

The character of the ^{3}H distribution in 2011 did not change considerably as compared with 2010. The 2011 curve, like the 2010 curve, has two peaks of maximal values, but the values of ^{3}H specific activity in 2011 are an order of magnitude higher than the 2010 values and are equal to 200,000 Bq/kg and 120,000 Bq/kg, respectively. The peaks in the curves are shifted, in 2010 peaks of maximal values correspond to 3.5 km and 4.7 km, in 2011 the peaks were located in points 5 km and 6 km. The data for the section 53-84 km were obtained; they show two areas with increased tritium concentration. The fact of ^{3}H inflow to the Irtysh River with the waters of the Shagan River was fully confirmed by the results of the 2011 investigations.

In 2011, monitoring of the Shagan River was carried out in order to study the dynamics of tritium contamination of surface waters. 5 monitoring posts were organized, where radionuclide composition of riverbed waters was studied during spring-summer period. Point 1 – M-24 (4 km) is the point where the values of ^{3}H specific activity sharply increase; points 2 and 3 – M-26 (5 km) and M-31/1 (6 km) are the points of ^{3}H maximal activity; point 4 – 38 km is characterized by the decrease in the ^{3}H specific activity; point 5 – 110 km is the point where the Shagan River inflows into the Irtysh River. The results of monitoring of the ^{3}H specific activity are presented in the table (Table 4).

Table 4.

Results of laboratory analyses

№	Sampling point	Activity ^{3}H, Bq/kg				
		16.05.2011	15.07.2011	05.08.2011	22.08.2011	15.09.2011
1	M-24 (4 km)	10,000 ± 1,000	7,200± 700	8,000 ± 800	10,000 ± 1,000	100,000 ± 10,000
2	M-26 (5 km)	200,000 ± 20,000	20,000 ± 2,000	10,000 ± 1,000	20,000 ± 2,000	60,000 ± 6,000
3	M-31/1 (6 km)	120,000 ± 10,000	17,000 ± 2,000	15,000 ± 1,000	30,000 ± 3,000	15,000 ± 1,000
4	38 km	250 ± 20	280 ± 30	150 ± 10	150 ± 10	300 ± 30
5	110 km	50± 5	30± 3	45 ± 4	< 13	45 ± 4

The most noticeable are the three points with maximal values registered in spring during floods. The value of the ^{3}H specific activity in the point M-24 (4 km) practically did not change during sampling period. The ^{3}H specific activity in the points M-26 (5 km) and M-31/1 (6 km) changed synchronously, maximal values were registered in May (200,000 Bq/kg in the point M-26 (5 km)) and minimal – in August. The only exception is the results obtained in September where the maximal value of 100,000 Bq/kg was registered in point M-24 (4 km).

The results of surface water monitoring showed that the value of ^{3}H specific activity in the point M-24 (4 km) practically did not change during the sampling period. ^{3}H specific activity in the points M-26 (5 km) and M-31/1 (6 km) changed synchronously, maximal values were registered in May (200,000 Bq/kg in the point M-26 (5 km)) and minimal values in August. The only exception is the results obtained in September, where the maximal value equal to 100,000 Bq/kg was registered in the point M-24 (4 km). It is supposed that ^{3}H-contaminated ground waters are discharged in the riverbed in several places. The obtained data show the dependence of such discharges on climatic conditions. As a whole, a decrease in the ^{3}H activity is registered during floods.

CONCLUSIONS

The 2011 investigations did not detect a source of contamination of surface waters by ^{90}Sr. Therefore in 2012 it is necessary to carry out investigations of ^{90}Sr concentration in the "Atomic Lake" waters, soils along the shores of the Shagan River, bottom sediments and ground waters.

In 2011 the maximal value of ^{3}H specific activity equal to 200,000 Bq/kg was registered during the flood at a distance of 5km from the Atomic Lake. A specific feature of tritium

contamination of the Shagan riverbed is relocation of the place of ^{3}H maximal concentration. Therefore it is necessary to localize the area of inflow and outflow of contaminated ground waters in the Shagan riverbed. It is recommended to expand the existing monitoring points in key areas and to enlarge the volume of works to carry out control of the state of riverbed waters (in addition to radionuclide analysis it is necessary to carry out microelement analysis, general chemical analysis and to determine water discharge). It is also necessary to carry out monitoring not in separate points but in the sections of maximal values. This will enable specialists to obtain a more precise picture of seasonal variations in tritium distribution.

It has been confirmed that ^{3}H presence with the concentration of 50 Bq/kg in the Shagan waters was registered along the whole riverbed downstream to the point of the river inflow into the Irtysh River. The ^{3}H inflow into the Irtysh River was registered practically during the whole spring-summer period.

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ШАҒАН ӨЗЕНІ СУЛАРЫНЫҢ РАДИОАКТИВТІ ЛАСТАНУЫ (2011-ші ЖЫЛҒЫ НӘТИЖЕЛЕР БОЙЫНША)

Айдарханов А.О., Лукашенко С.Н., Генова С.В., Ляхова О. Н., Айдарханова А.К.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Мақалада, Шаған өз. суларының радиоактивті ластану деңгейі мен сипатын зерттеу нәтижелері келтірілген. Шаған өз. суларындағы ^{90}Sr маңызды түрде шоғырлануы «Атом көлімен» тікелей байланысты емес екені анықталды. Шаған өзені бойымен «Атом көлінен» Ертіс өзенінің суларына құйылғанға дейін судағы тритийдің орын алғаны анықталды, бұл жердегі оның тиесілі белсенділігі 50 Бк/кг-ны құрады. Арнадағы суларда тритийдің максималды құрамы көктемде орын алды және 20 кБк/кг-ны құрады.

Түйінді сөздер: Шаған өзені, радиоактивті ластану, тритий, «Атом көлі».

РАДИОАКТИВНОЕ ЗАГРЯЗНЕНИЕ ВОД РЕКИ ШАГАН (ПО РЕЗУЛЬТАТАМ 2011-го ГОДА)

Айдарханов А.О., Лукашенко С.Н., Генова С.В., Ляхова О.Н., Айдарханова А.К.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В статье приведены результаты исследований характера и уровней радиоактивного загрязнения вод р. Шаган. Выявлено, что наличие значимых концентраций ^{90}Sr в водах р. Шаган не связано напрямую с «Атомным озером». Установлено присутствие трития в воде на всем протяжении р. Шаган от «Атомного озера» до впадения в р. Иртыш, где его удельная активность составила 50 Бк/кг. Максимальные значения трития в русловых водах пришлись на весенний период и составили 200 кБк/кг.

Ключевые слова: река Шаган, радиоактивное загрязнение, тритий, «Атомное озеро».

УДК 577.4:504.064:622.271.8:539.16

RADIOLOGICAL CONDITIONS IN NEAR-PORTAL AREAS OF TUNNELS AT THE DEGELEN MOUNTAIN MASSIF BEFORE AND AFTER WORKS ON STRENGTHENING OF PHYSICAL BARRIERS

Korovikova T. V., Mustafina E. V., Ossintsev A. Yu., Dmitropavlenko V. N., Yakovenko Yu. Yu.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

In 2009-2010, within the conservation works on elimination of the nuclear tests infrastructure aimed at nuclear weapons proliferation threat reduction, eight tunnels at the Degelen mountain massif of the Semipalatinsk test site were re-sealed. The purpose of present radioecological research was to assess the state of the environment as well as possible negative impact of conservation works on the near-portal areas of the tunnels. The paper reports on the changes in radioecological situation at the near-portal areas of each controlled tunnel.

Keywords: Semipalatinsk test site, Degelen mountain massif, tunnels, additional protection for engineering structure, radiological survey, radiation situation, equivalent dose rate, the flux of α-, β-particles, radionuclides, specific activity, areal contamination

INTRODUCTION

At the end of the 1990s, measures aimed at liquidation of the infrastructure of nuclear tests were taken on the territory of the Semipalatinsk Test Site. The following-up inspection of the state of engineering constructions on the Degelen test ground (2001-2005) discovered breaking or violation of protective barriers on engineering constructions with carry-over of nuclear active wastes (NAW) to the daylight surface. In order to reduce the threat of NAW spreading, in 2009-2010 additional protection of 8 tunnels was construction.

One of the papers, published in 2010 in the Collection of Papers of the Institute of Radiation Safety & Ecology for 2007-2009, described the influence of works on additional protection of 9 tunnels in the Degelen mountain massif carried out in the period from September 2006 to December 2009 on radiation situation in the near-portal areas [1]. The present paper continues that research and describes the influence of the 2009-2010 works on additional protection of engineering constructions on radiation situation in the near-portal areas of 8 tunnels.

1. BACKGROUND INFORMATION

The area of works, the Degelen mountain massif, is a dome-shaped hill of about 18 km in diameter with difference in heights up to 300 m. According to its geographical position, the Degelen mountain massif is located in the northeastern part of Kazakh Hummocks on the territory of the former Semipalatinsk Test Site. The scheme of location of objects on the Degelen test ground and photographs of the tunnel portals before the works are shown in the figure below (Figure 1).

1.1. Methods of additional protection of the engineering structures (2009-2010)

Construction of additional protection of engineering structures consisted in filling tunnel voids by the binding material preventing the possibility of unauthorized NAW extraction. Depending on the initial data for the engineering assignment, the additional protection was constructed using two different techniques:

- Construction of additional protection of engineering structures through vertical boreholes drilled from the surface of the mountain massif – a vertical method;
- Construction of additional protection of engineering constructions by drilling-in of the portal of the structure with further excavation from tunnels – a horizontal method.

Depending on the method of additional protection the tunnels were assigned the following notations:

- Tunnels with a horizontal construction of additional protection – G5, G6;
- Tunnels with a vertical construction of additional protection – V6, V7, V8, V9, V10;
- Tunnels with a combined construction of additional protection (horizontal and vertical) – GV1.

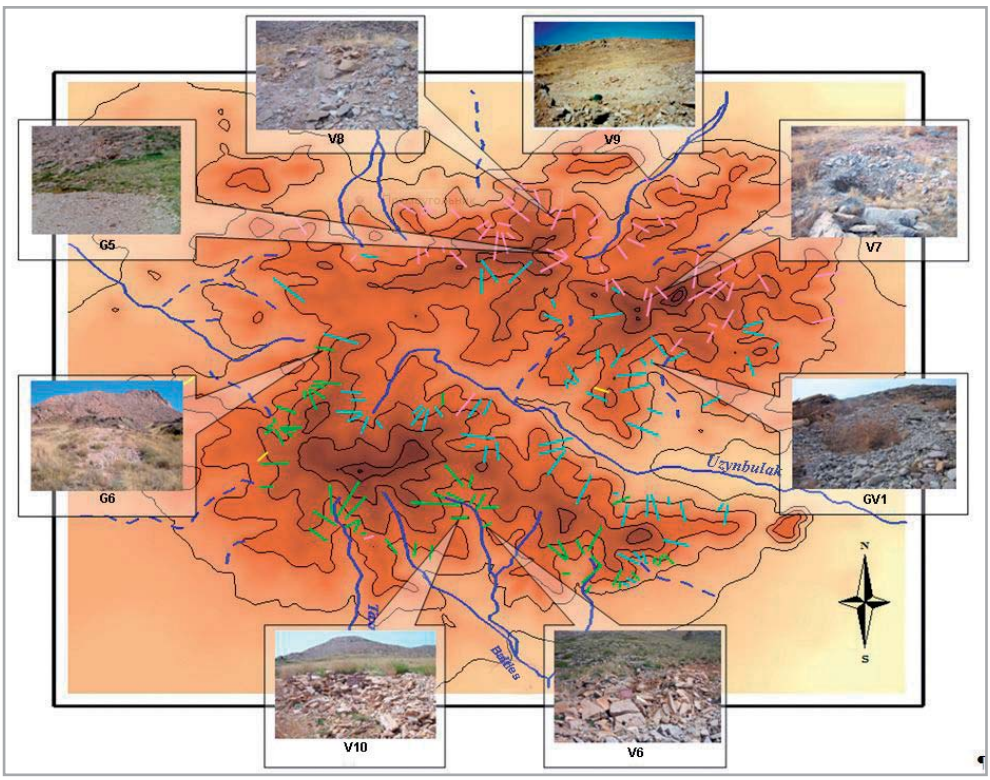


Figure 1. Location of the tunnels at the Degelen test ground

1.2. Characteristics of the radioactive contamination sources

The data from literature sources [2, 3] on the tests made in the studied tunnels are presented in the table (Table 1). In the tunnels with notations V7, V8, V10 and G5 group explosions with several charges were made. The aim of the tests was development or modernization of nuclear weapons (NWM), carrying out of fundamental or methodological research (FMR), studying of accidental regimes and nuclear incidents (ARNI).

Table 1.

Information on tests made in tunnels G5, G6, V6 – V10, GV1 in the Degelen mountain massif

Tunnel code	Yield of nuclear explosion, kton	Characteristic of explosion	Aim of tests	Radiation situation
Г5	Up to 20 kton	Group nuclear explosion consisting of 2 explosions	NWM	
	0.001 kton		ARNI	ICE
Г6	Up to 20 kton		NWM	CCE
В6	Up to 20 kton		NWM	CCE
	Less than 0.01 kton		ARNI	CCE
В7	Up to 20 kton	Group NE consisting of 3 explosions	NWM, ARNI	CCE
В8	Up to 20 kton	Group NE consisting of 3 charges	NWM, FMR	CCE
	Up to 20 kton	Group NE – 1 explosion in tunnel F, 3 explosions in tunnel 141	NWM	CCE
В9	Up to 20 kton		NWM	ICE
	Less than 0.001 kton		ARNI	
В10	Up to 20 kton	Group NE consisting of 2 explosions	NWM	CCE
	Up to 20 kton		NWM	CCE
	Up to 20 kton		NWM	ICE
	Up to 20 kton			CCE
ГВ1	Up to 20 kton		FMR	CCE
	Up to 20 kton		FMR	ICE
	Up to 20 kton		FMR	ICE

NWM – development or modernization of nuclear weapons,
FMR – fundamental or methodological research
ARNI – investigations of accidental regimes и nuclear incidents
INF – investigations of nuclear effects of nuclear substances and their impact on military and civil objects
CCE – an explosion of a complete camouflet, ICE – an explosion of an incomplete camouflet

According to the initial data, it can be supposed that sources of radioactive contamination are fission fragments of ^{239}Pu and remains of fissionable material. In tunnel V9 either an incomplete camouflet of a capacity of 20 ktons plus a hydronuclear test or a chemical blasting of a nuclear charge was made. It is impossible now to estimate the contribution of such explosions, and therefore calculations were made for nominal tests which form the lower level of residual activity.

Additional radioactive contamination of the territory of tunnel G5 was made by the second explosion of a yield 0.001 ktons, which according to the characteristics of the explosion was mainly caused by Pu and ^{241}Am isotopes. Concentrations of radionuclides emitted in the explosion are commensurable with concentrations from the 20 kton explosion.

Mass emissions of fragments of instantaneous fission of ^{239}Pu have been well studied and are widely presented in literature [4]. Based on this fact and on the initial data about the explosion, we carried out calculations of activity taking into account the half-life period of the ^{239}Pu fission fragments, which make a significant contribution to the total activity (Table 2).

The amount of remaining fissionable material by the time when the nuclear charge construction is destroyed is determined by the efficiency of a nuclear explosion. The efficiency of the nuclear explosion, depending on the time of tests, type and construction of the nuclear device, may vary from 1 to 30 %. In order to calculate the amount of remaining fissionable substance, due to the absence of information on that nuclear explosion, the efficiency was taken equal to 20 %.

According to theoretical calculations, the ^{239}Pu activity per 1 kg of explosion at the moment after explosion t=0 is $4.8 \cdot 10^{11}$ Bq/kton. Knowing a typical composition of the weapon Pu, it is possible to calculate the activity of other isotopes in the substance of the charge (Table 2).

The well-known data on neutron activation show that most isotopes produced in the process of activation have a rather short half-life period. Therefore taking into account a rather long period of time that e passed after the explosion, it is possible to suppose that contribution of activation products to total gamma-activity is negligibly small. The only exception may be ^{60}Co, ^{152}Eu and ^{154}Eu, but it is impossible to calculate their activity at the present moment of time. Therefore, in laboratory investigations of the samples taken in vicinity of the tunnels, it is necessary to take into account the possibility of presence of a certain radionuclide and to estimate its contribution to the radiation situation on the territory of the tunnel.

Therefore, increased concentrations of the radionuclides ^{90}Sr, ^{99}Tc, ^{137}Cs, ^{151}Sm, ^{241}Am and Pu are to be expected in the near-portal areas.

Table 2.

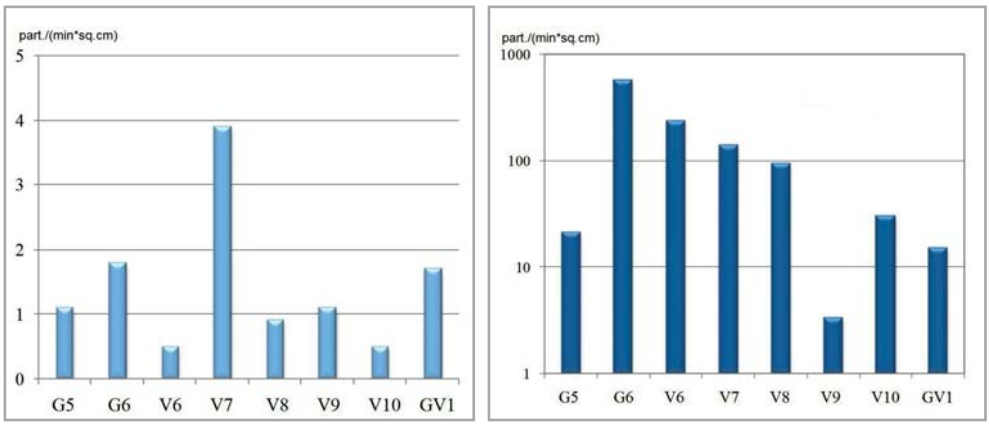
Calculated activity of ^{239}Pu fission fragments and residua of fissionable substance in tunnels G5, G6, V6-V-10, GV1 of the Degelen mountain massif, Bq

	Г5	Г6	В6	В7	В8	В9	В10	ГВ1
Se-79	2.1×10^{8}	2.9×10^{7}	$2.2\cdot10^{8}$	3.8×10^{7}	3.3×10^{8}	3.1×10^{7}	1.7×10^{8}	6.7×10^{8}
Sr-90	$3.9\cdot10^{13}$	1.8×10^{13}	$5.1\cdot10^{13}$	2.4×10^{13}	3.2×10^{13}	1.9×10^{13}	1.0×10^{14}	6.9×10^{13}
Y-90	$3.9\cdot10^{13}$	1.8×10^{13}	$5.1\cdot10^{13}$	2.4×10^{13}	3.2×10^{13}	1.9×10^{13}	1.0×10^{14}	6.9×10^{13}
Nb-93m	1.2×10^{7}	1.8×10^{7}	$1.7\cdot10^{9}$	2.4×10^{9}	1.7×10^{9}	1.9×10^{9}	1.0×10^{10}	7.4×10^{7}
Sn-121m	$2.0\cdot10^{10}$	2.7×10^{10}	$2.3\cdot10^{10}$	3.5×10^{10}	4.0×10^{10}	2.8×10^{10}	1.5×10^{11}	8.8×10^{10}
Sb-125	7.7×10^{8}	2.4×10^{8}	$9.1\cdot10^{9}$	3.1×10^{8}	4.0×10^{10}	2.8×10^{8}	1.4×10^{9}	1.3×10^{11}
I-129	7.7×10^{7}	1.0×10^{8}	7.7×10^{7}	1.3×10^{8}	1.1×10^{8}	1.1×10^{8}	5.7×10^{8}	2.3×10^{8}
Cs-135	$1.9\cdot10^{9}$	2.6×10^{9}	$1.9\cdot10^{9}$	3.3×10^{9}	2.7×10^{9}	2.6×10^{9}	1.4×10^{10}	5.5×10^{9}
Cs-137	$5.3\cdot10^{13}$	5.1×10^{13}	$6.6\cdot10^{13}$	6.6×10^{13}	8.9×10^{13}	5.3×10^{13}	2.8×10^{14}	1.9×10^{14}
Sm-151	$2.2\cdot10^{12}$	4.1×10^{12}	$2.4\cdot10^{12}$	5.3×10^{12}	5.3×10^{12}	4.2×10^{12}	2.3×10^{13}	1.1×10^{13}
Eu-154	1.2×10^{8}	1.1×10^{8}	$2.3\cdot10^{8}$	1.5×10^{8}	5.9×10^{8}	1.2×10^{8}	6.4×10^{8}	1.3×10^{9}
Eu-155	$1.4\cdot10^{10}$	2.6×10^{10}	$5.8\cdot10^{10}$	3.3×10^{10}	4.6×10^{11}	2.6×10^{10}	1.5×10^{11}	1.1×10^{12}
Tc-99	1.7×10^{10}	8.2×10^{11}	$1.7\cdot10^{10}$	1.1×10^{12}	3.4×10^{10}	$1.7\cdot10^{10}$	4.6×10^{12}	5.1×10^{10}
Pu-238	$2.4\cdot10^{11}$	3.4×10^{12}	$2.7\cdot10^{11}$	3.7×10^{12}	7.5×10^{12}	3.5×10^{12}	1.5×10^{13}	1.04×10^{12}
Pu-239	$9.6\cdot10^{12}$	9.8×10^{12}	$9.6\cdot10^{12}$	9.8×10^{12}	1.9×10^{13}	9.8×10^{12}	3.9×10^{13}	2.9×10^{13}
Pu-240	$2.2\cdot10^{12} - 2.4\cdot10^{12}$	3.2×10^{12}	$2.2\cdot10^{12} - 2.4\cdot10^{12}$	3.2×10^{12}	6.4×10^{12}	3.2×10^{12}	1.3×10^{13}	9.3×10^{12}

	Г5	Г6	В6	В7	В8	В9	В10	ГВ1
Pu-241	$6.8 \cdot 10^{12} - 1.4 \cdot 10^{13}$	3.1×10^{13}	$1.1 \cdot 10^{13} - 2.3 \cdot 10^{13}$	5.3×10^{13}	1.1×10^{14}	3.3×10^{13}	2.6×10^{14}	8.8×10^{13}
Pu-242	$1.8 \cdot 10^{7}$	3.6×10^{7}	$1.8 \cdot 10^{7}$	3.6×10^{7}	7.2×10^{7}	1.8×10^{7}	1.4×10^{7}	5.5×10^{7}
Am-241	$1.1 \cdot 10^{12} - 2.3 \cdot 10^{12}$	6.5×10^{12}	$9.4 \cdot 10^{11} - 2.0 \cdot 10^{12}$	6.1×10^{12}	1.2×10^{13}	6.7×10^{12}	2.8×10^{13}	7.9×10^{12}

Radiological situation at the near-portal areas by the results of the 1999 investigations.

In the 1996-1998, the conservation operations at the Degelen tunnels were carried out. After sealing of the tunnels, radiometric measurements (1999) were made in the near-portal areas. A 20x20m mesh was used when measured EDR, and density of the flux of α- and β-particles in each point. In each tunnel 5 soil samples were taken. The results of the investigations are presented in the figures (Figure 2–3).



a) b)

Figure 2. Maximal values of the density of the flux of α-particles (a) and β-particles (b) by the results of the tunnel inspection in 1999.

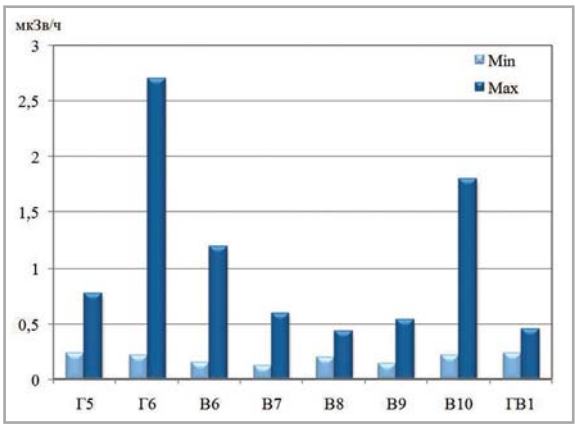


Figure 3. Maximal and minimal EDR values by the results of the tunnel inspection in 1999.

By the results of the 1999 radioecological surveying, the highest values of radiation parameters were registered in the tunnels G6 (EDR up to 2.7 μSv/h, the density of β-particle flux up to 570 part/(min·cm^2)) and V6 (EDR up to 1.2 μSv/h, the density of β-particle flux up to 235 part/(min·cm^2)). However, values exceeding maximal permissible values for the A category personnel were not registered in any of the tunnels [4].

Laboratory analyses of the soil samples show that the specific activity of radionuclides ^{90}Sr and $^{239+240}$Pu in the soil samples gathered after conservation works in the near-portal areas was not higher than the normative MSSA level for these radionuclides (MSSA for ^{137}Cs is $1\cdot10^4$ Bq/kg, ^{90}Sr – $1\cdot10^5$ Bq/kg, ^{241}Am – $1\cdot10^3$ Bq/kg, $^{239+240}$Pu – $1\cdot10^3$ Bq/kg, NRB-99 (radiation safety standards)). The only exception were spots in tunnels V7 and G6 with radioactive contamination with increased concentration of ^{241}Am ($4.1\cdot10^3$ Bq/kg, V7) and ^{137}Cs ($5.8\cdot10^4$ Bq/kg, G6). Maximal values of specific activities of radionuclides after tunnels conservation in 1999 are presented in the figure (Figure 4).

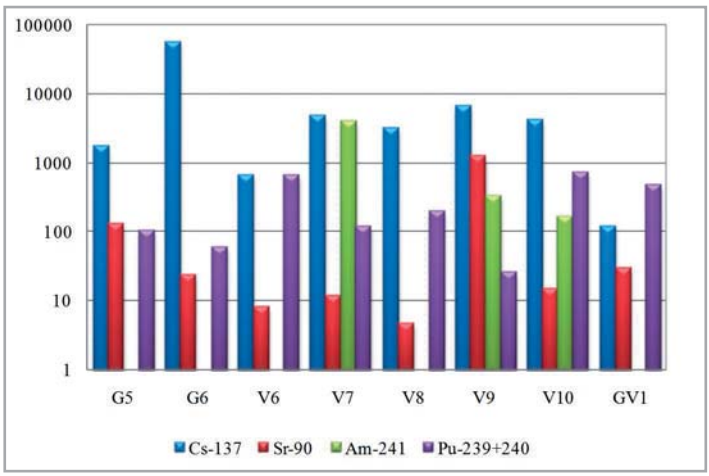


Figure 4. Maximal values of radionuclide specific activities after conservation works registered during final inspection of tunnels in 1999, Bq/kg.

1.3. Conclusions of the 1999 tunnel inspection

According to the results of the 1999 final inspection of the tunnels, maximal registered values of radiation parameters did not exceed maximal permissible values for the A category personnel [5]. By the data of laboratory analyses, the increased values of specific activities for artificial radionuclides were only registered in two tunnels – G6 and V7.

2. MAJOR FACTORS INFLUENCING FORMATION OF RADIOLOGICAL SITUATION DURING CONSTRUCTION OF ADDITIONAL PROTECTION

Factors influencing formation of radiation situation can be conventionally subdivided into 3 groups depending on the type of additional protection [1]:

- General factors not depending on the type of additional protection (radioactive contamination of the surface of the working area, objects with increased radiation hazard located in a close proximity to the area);
- Factors characteristic of the vertical method (possible contamination of the working area due to the carryover of the radioactive contamination from the body of the tunnel or adjacent rocks with bore mud and rise of dust, redistribution of existing radioactive contamination caused by secondary transfer due to dust rise from piles, motion of equipment and personnel);
- Factors characteristic of the horizontal method (probable carryover of the radioactive contamination from the body of the tunnel with the removed rock refuse formed during tunnel excavation, rise of radioactive aerosols during tunnel ventilation, redistribution of existing radioactive contamination caused by secondary transfer by equipment and personnel both from the body of the tunnel and from the piles of refuse removed from the tunnel).

3. RADIOLOGICAL SURVEYING METHODOLOGY

At the stage of planning of field and laboratory investigations in the near-portal areas of the tunnels, the initial and calculated data enabled us to suppose that as a result of possible carryover of radionuclides from the tunnel to the surface, the territory of the tunnel and adjacent areas could be mainly contaminated with the following radionuclides: ^{90}Sr, ^{137}Cs, ^{151}Sm, ^{241}Am and Pu isotopes.

According to theoretical recommendations, field works and samplings were carried out using a uniform mesh with measurements of EDR and surface ground contamination with α- and β-particles in fixed points and EDR measurements in the "Search" regime between points. On the territory of tunnels, where it was planned to use a vertical method for additional protection, additional EDR measurements in the "Search" regime were made starting from the cutting-in point in the segment, of about 50m wide and 250 m long, located along the tunnel axis [1].

Environmental samples were taken in the following points:

- on the projected working area – point soil sampling:
- on the territory of the projected field camp – point soil sampling;
- in the points located uniformly on the studied area – point soil sampling (an approximate number of sampling points is 5-8% of the total number of points where radiation parameters are measured);
- on piles and backfilling of tunnels – combined soil sampling;
- in the places of maximal values of radiation parameters – point soil sampling;
- a projected cutting-in point – samples of water vapor and aerosols.

For laboratory analyses gamma-, beta- and alpha-spectroscopic equipment was used.

The final inspection was made according to the scheme similar to the preliminary inspection.

4. RADIOLOGICAL CONDITIONS AT THE NEAR-PORTAL AREAS OF THE TUNNELS BEFORE THE WORKS (2009)

4.1. Radiological situation according to the results of radiometry and dose measurements

By the results of the preliminary inspection, schematic maps of radiation parameters distributions in the studied areas were made (Figure 7a – Figure 22a). The data on maximal and minimal EDR values registered during the preliminary inspection of the tunnels are presented in the histogram (Figure 5).

Minimal values of the β-flux density registered during the preliminary inspection of the territory of the near-portal areas did not exceed 10 part/(min·cm^2). Maximal values of the β-flux density registered during the preliminary inspection are presented in the histogram (Figure 6).

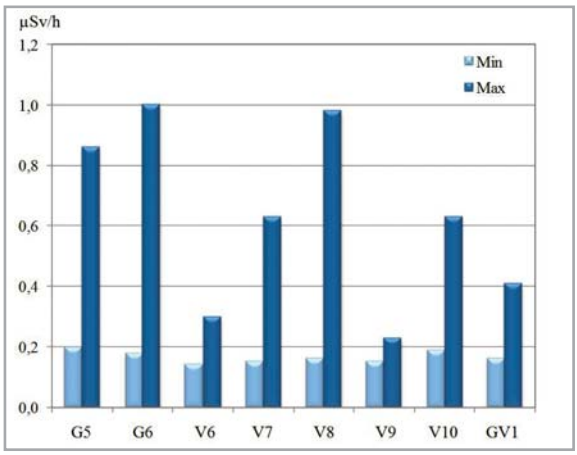


Figure 5. Maximal and minimal EDR values during the preliminary tunnel inspection

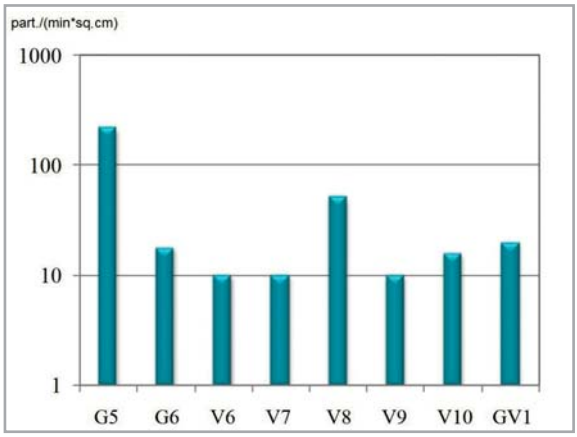
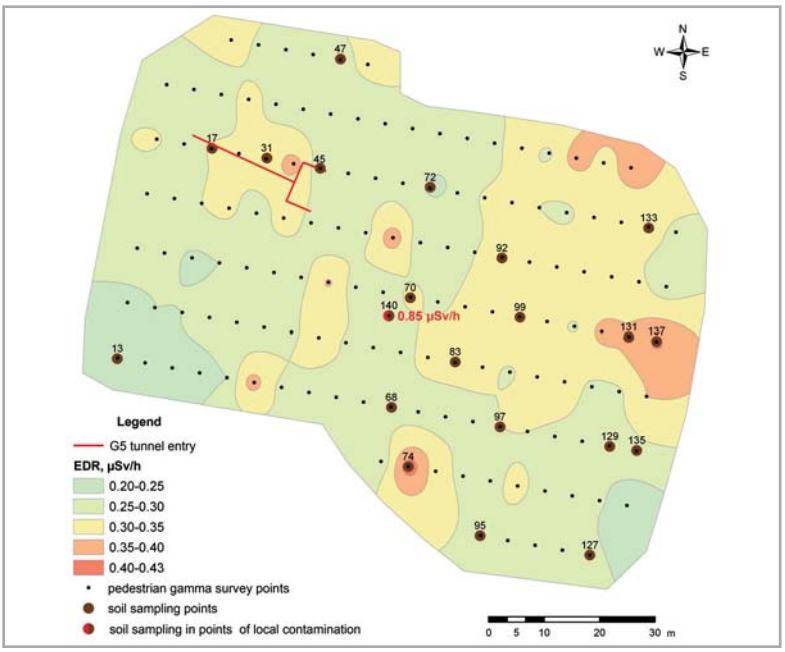
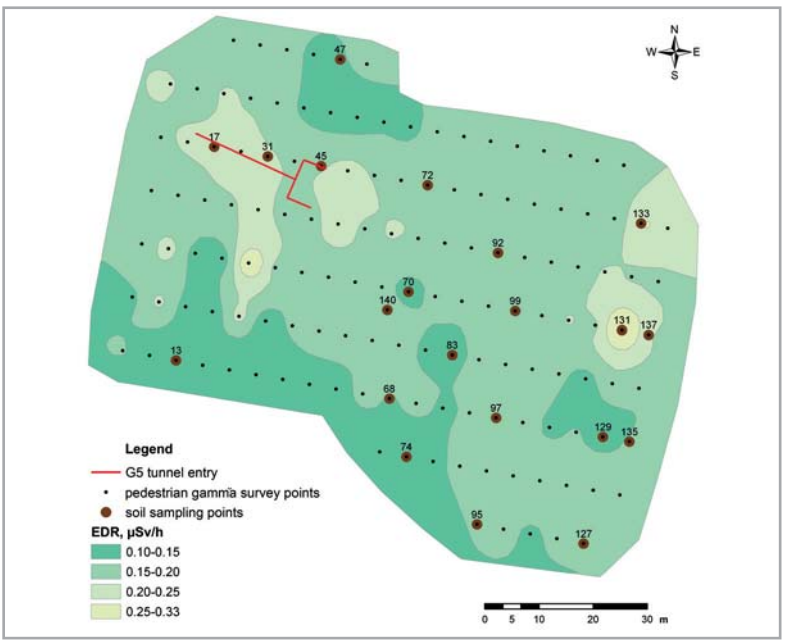


Figure 6. Maximal values of the β-flux density during the preliminary tunnel inspection

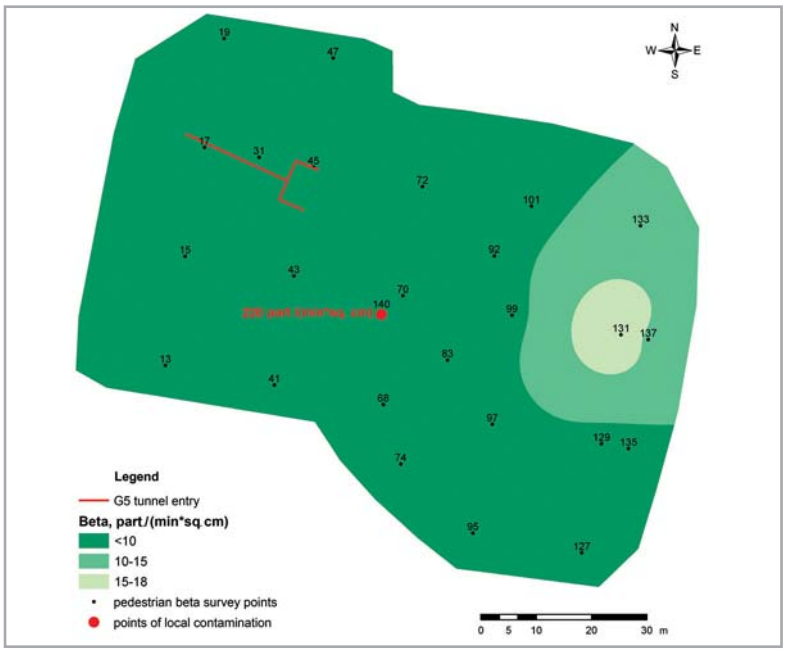


a)

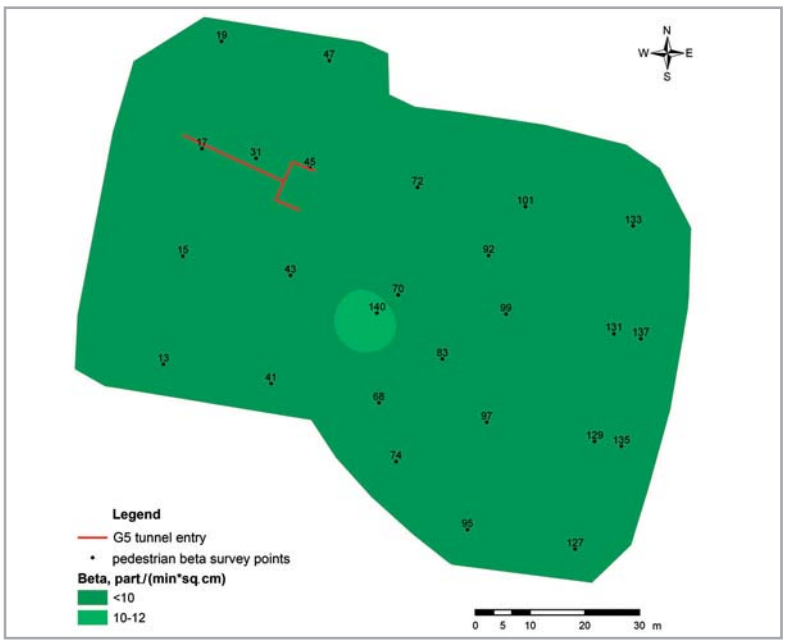


b)

Figure 7. Schematic maps of EDR distribution on the territory of the near portal areas of tunnel G5 during preliminary (a) and final (b) inspections

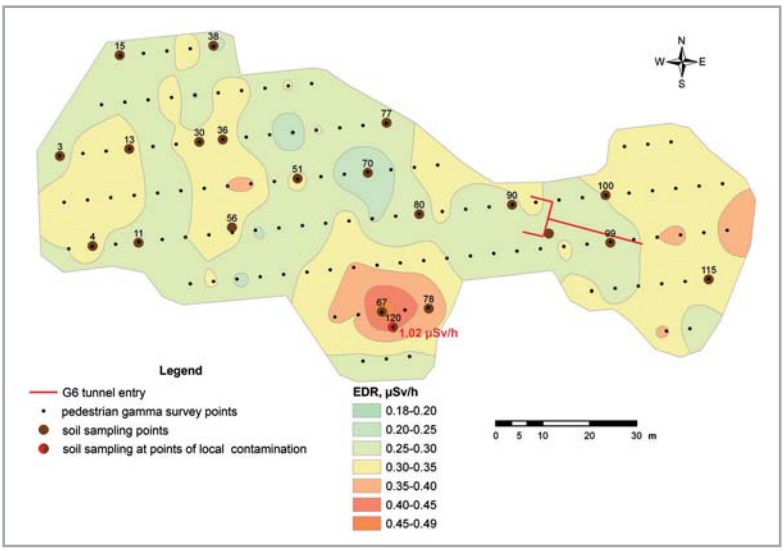


a)

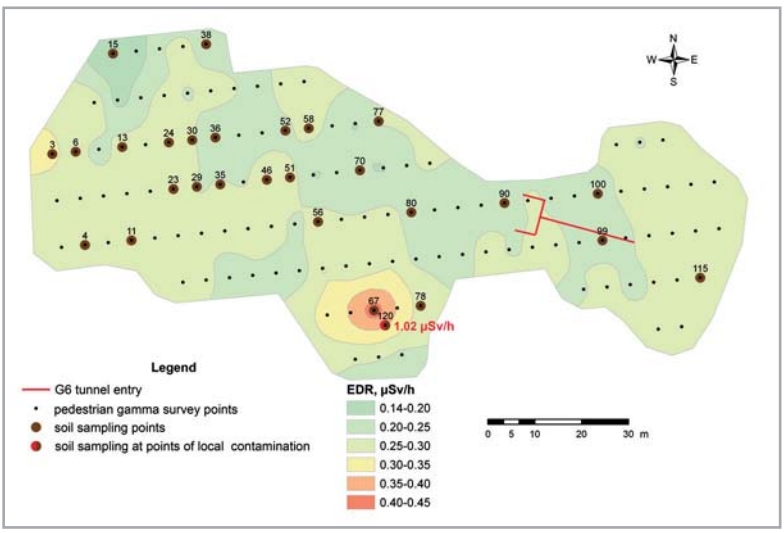


b)

Figure 8. Schematic maps of distribution of the density of β-particles flux on the territory of the near portal area of tunnel G5 during preliminary (a) and final (b) inspections



a)

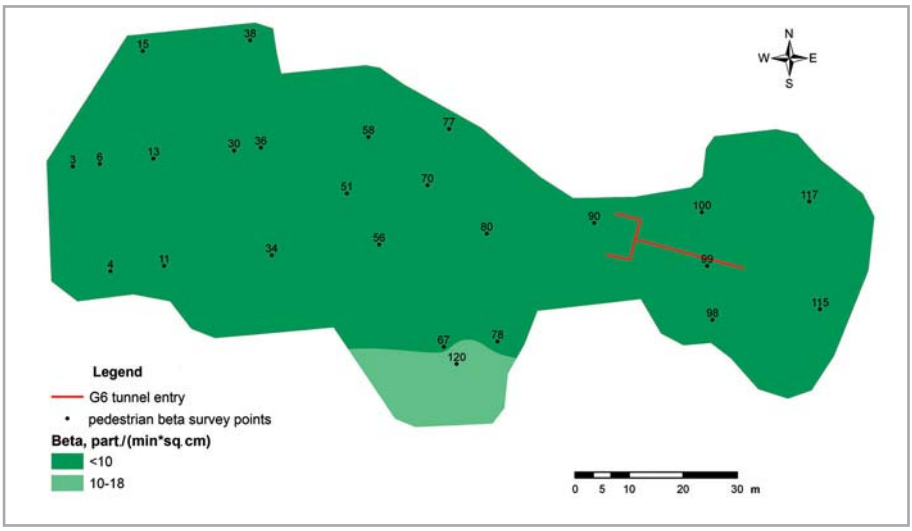


b)

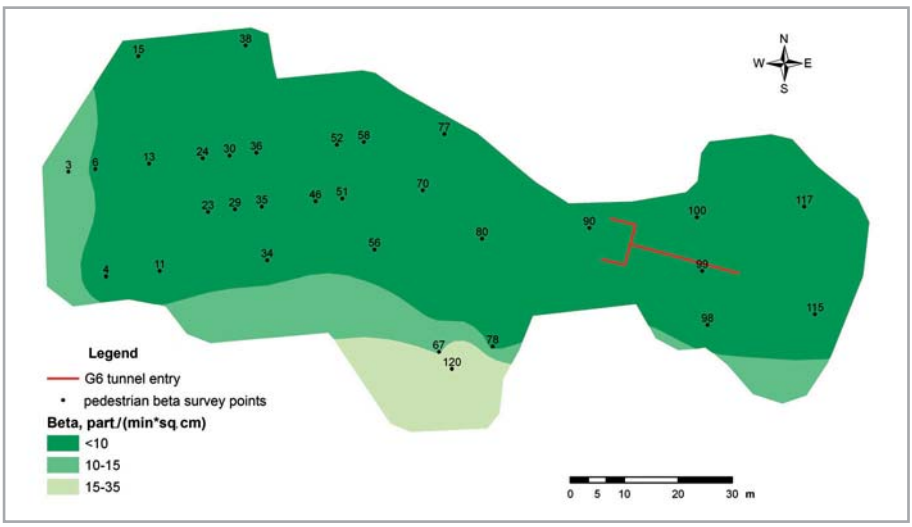
Figure 9. Schematic maps of EDR distribution on the territory of the near portal area of tunnel G6 during preliminary (a) and final (b) inspections

Densities of fluxes of α-particles registered during the preliminary inspection in all inspected areas did not exceed the detection limit of used measuring instruments (1 part/(min·cm^2)). According to the preliminary inspection, maximal radiation parameters were registered on the territory of near-portal areas of tunnels G6 (EDR – 1.02 μSv/h) (Figure 9a), V8 (EDR – 0.98 μSv/h) (Figure 15a), G5 (EDR – 0.86 μSv/h), the density of the

flux of β-particles was 220 part/(min·cm^2)) (Figure 7a, Figure 8a). The results of inspection made after completion of works on construction of additional protection show that on the territory of all tunnels the radiation parameters did not exceed maximal permissible values for the A category personnel [5].

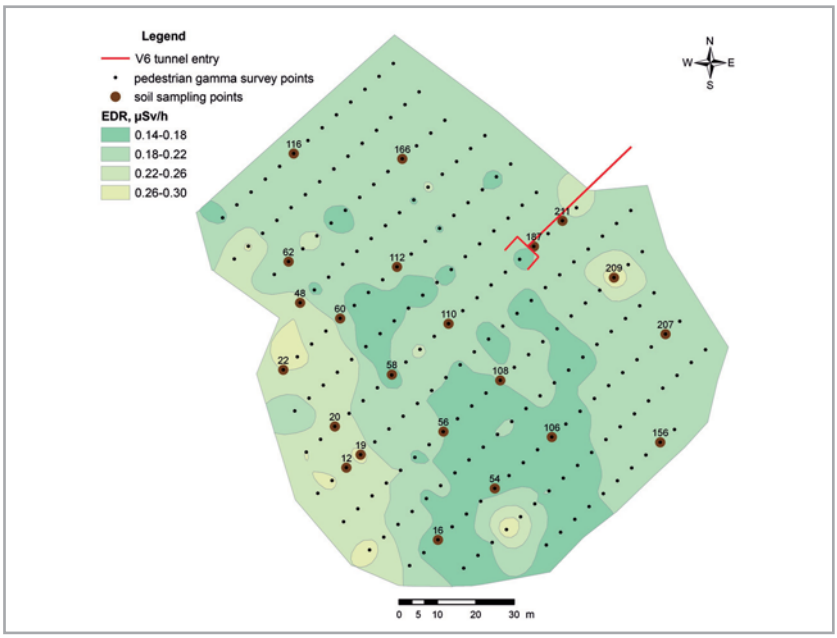


a)

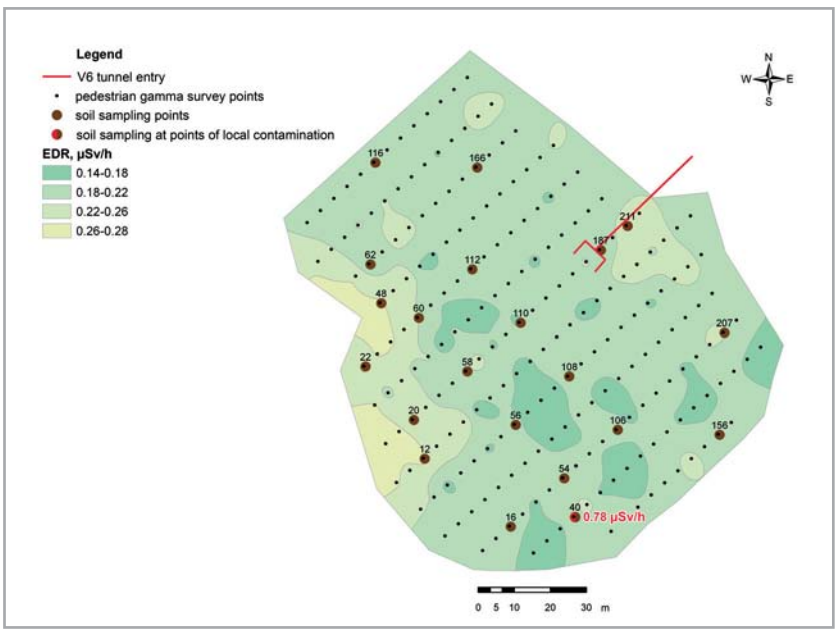


b)

Figure 10. Schematic maps of distribution of the density of β-particles flux on the territory of the near portal area of tunnel G6 during preliminary (a) and final (b) inspections

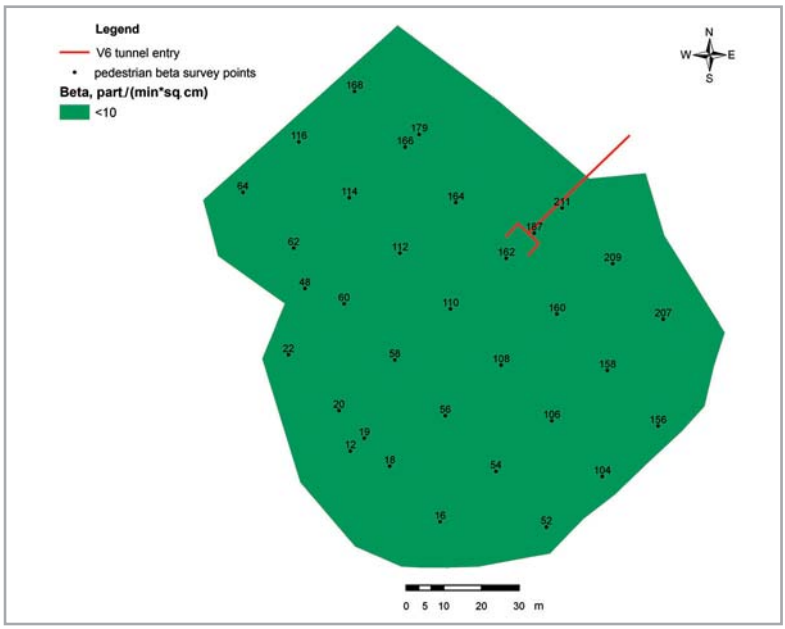


a)

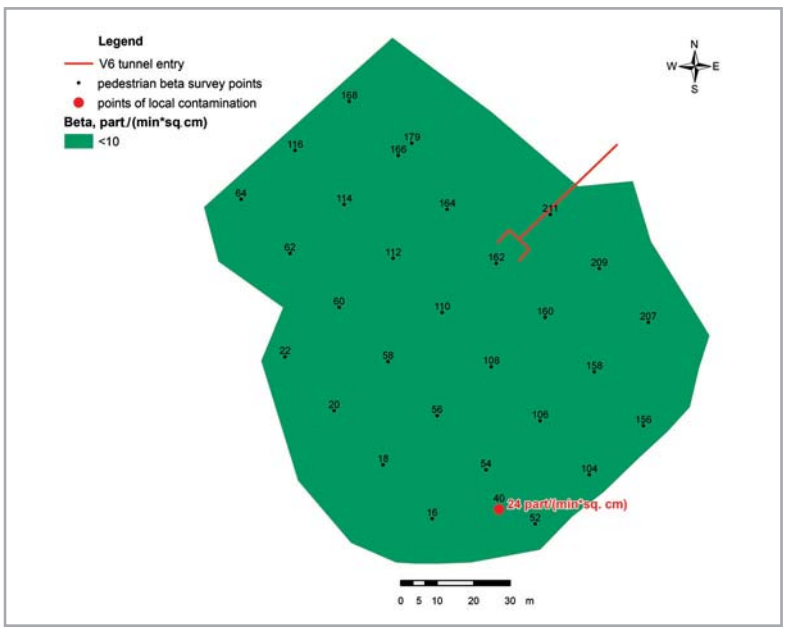


b)

Figure 11. Schematic maps of EDR distribution on the territory of the near portal area of tunnel V6 during preliminary (a) and final (b) inspections

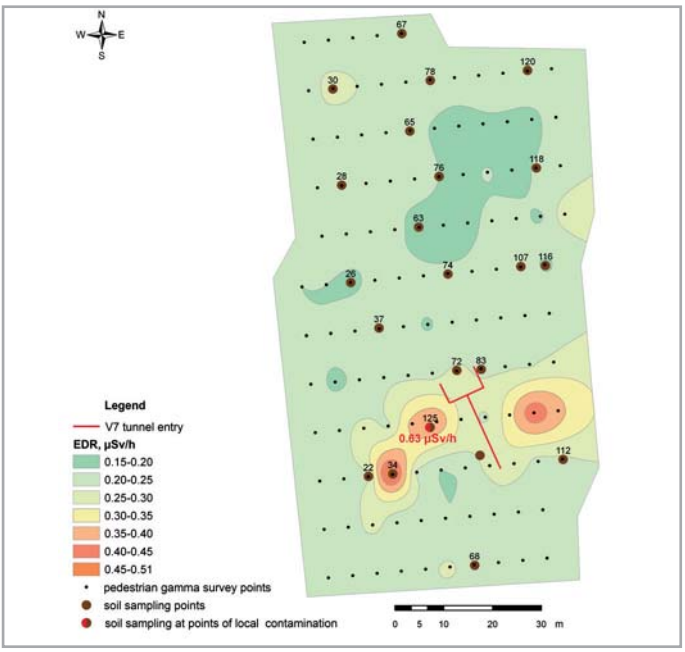


a)

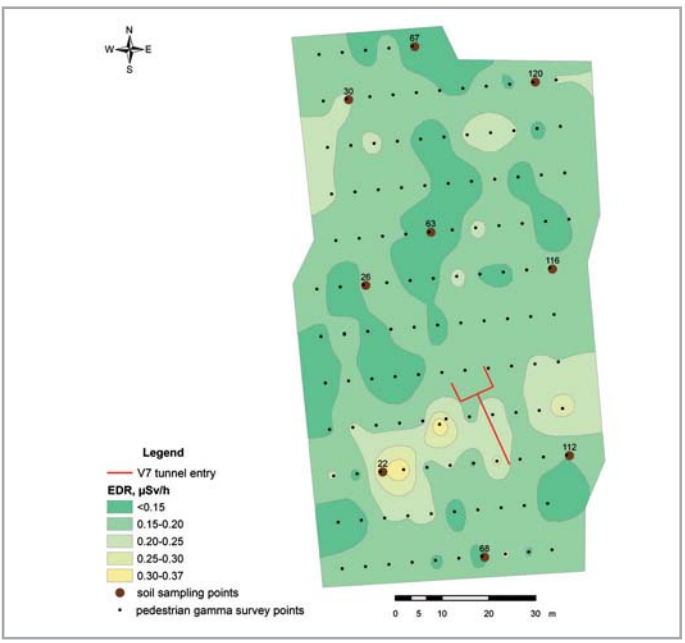


b)

Figure 12. Schematic maps of distribution of the density of β-particles flux on the territory of the near portal area of tunnel V6 during preliminary (a) and final (b) inspections



a)



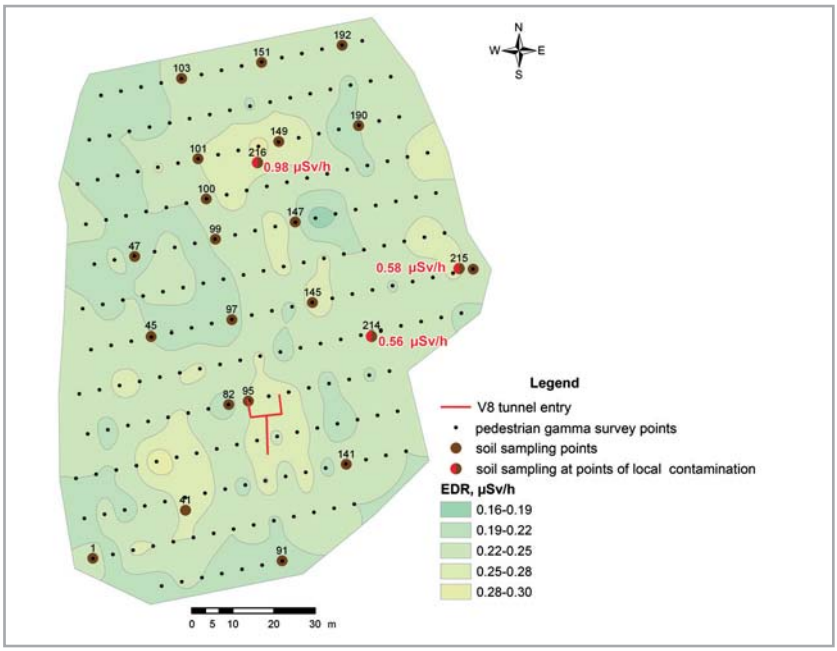
b)

Figure 13. Schematic maps of EDR distribution on the territory of the near portal area of tunnel V7 during preliminary (a) and final (b) inspections

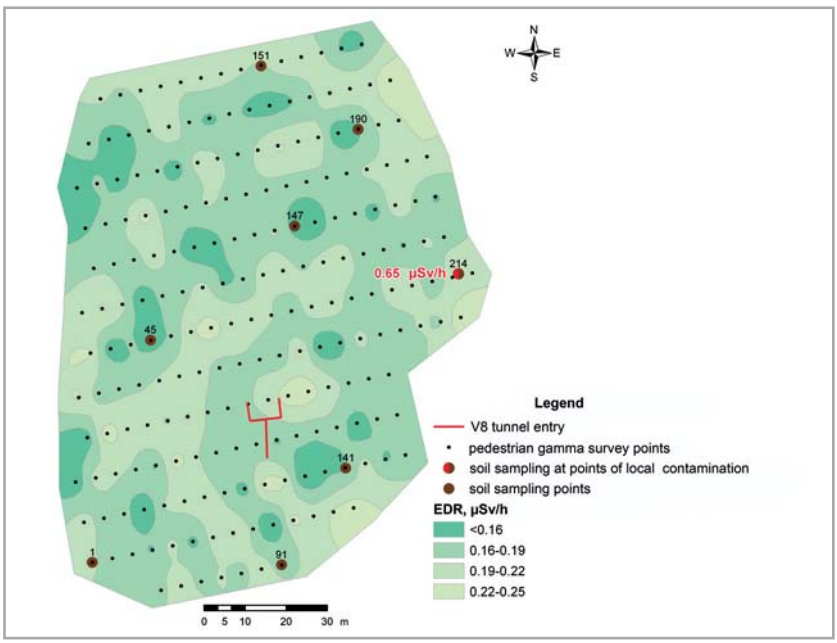
a)

b)

Figure 14. Schematic maps of distribution of the density of β-particles flux on the territory of the near portal area of tunnel V7 during preliminary (a) and final (b) inspections

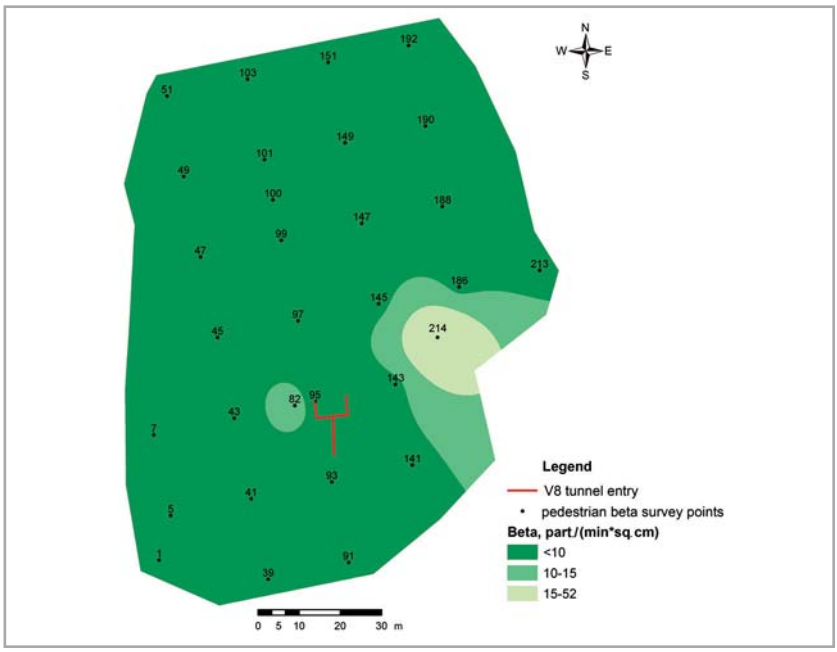


a)

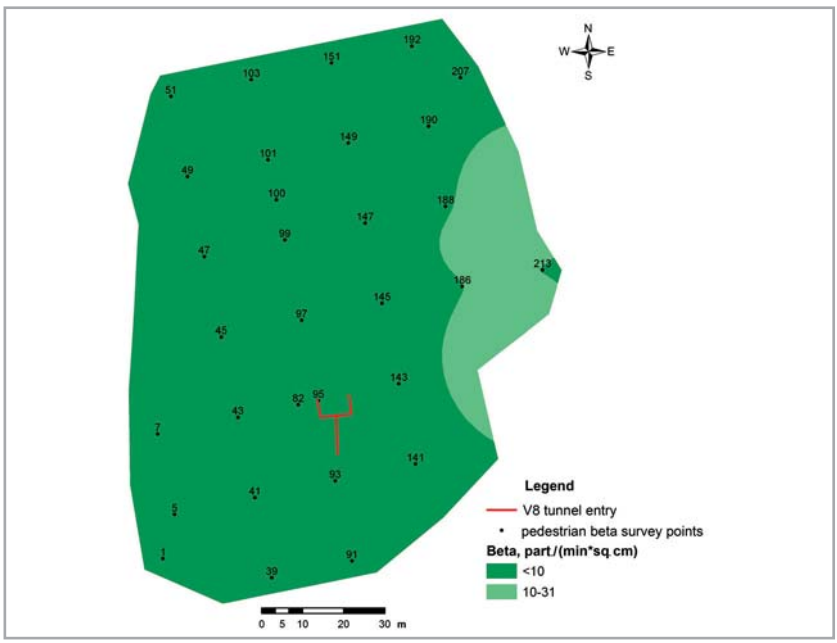


b)

Figure 15. Schematic maps of EDR distribution on the territory of the near portal area of tunnel V8 during preliminary (a) and final (b) inspections

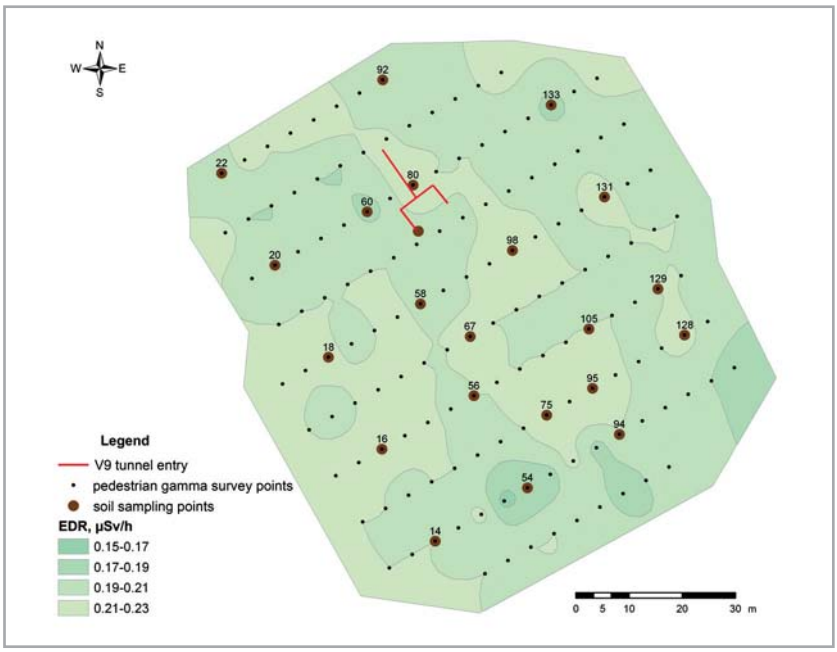


a)

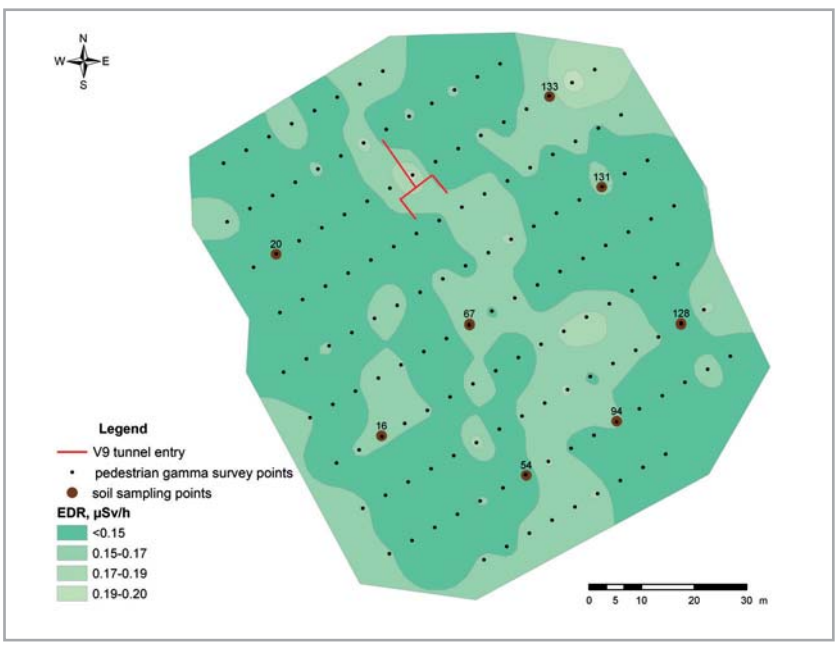


b)

Figure 16. Schematic maps of distribution of the density of β-particles flux on the territory of the near portal area of tunnel V8 during preliminary (a) and final (b) inspections

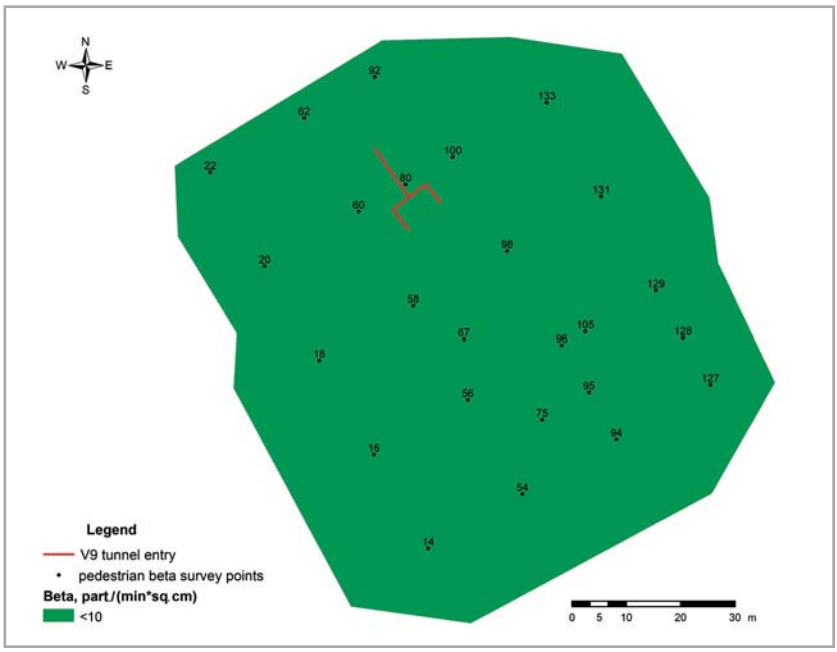


a)

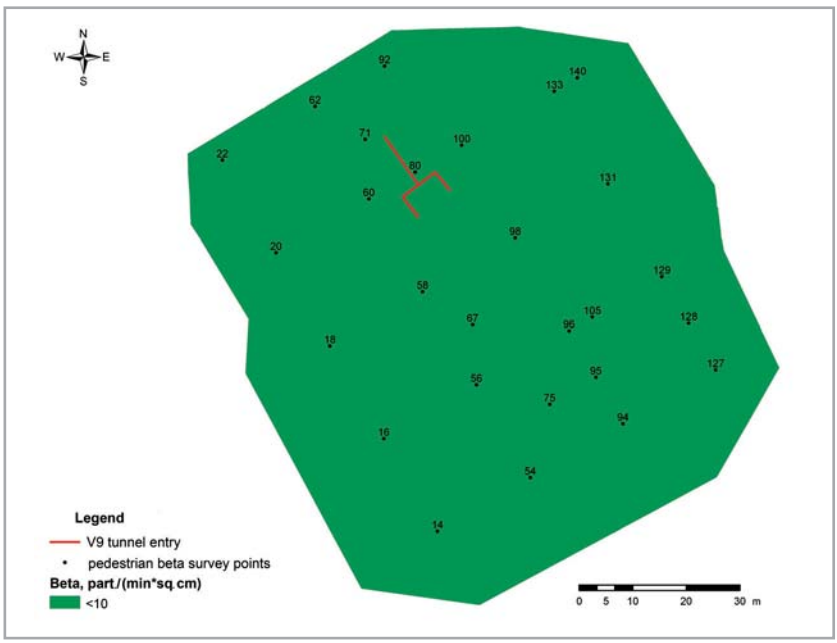


b)

Figure 17. Schematic maps of EDR distribution on the territory of the near portal area of tunnel V9 during preliminary (a) and final (b) inspections

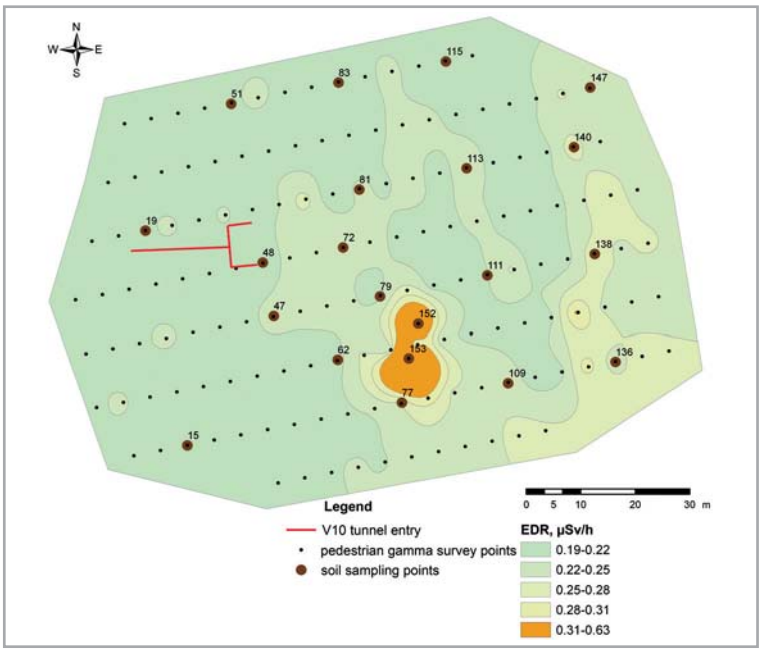


a)

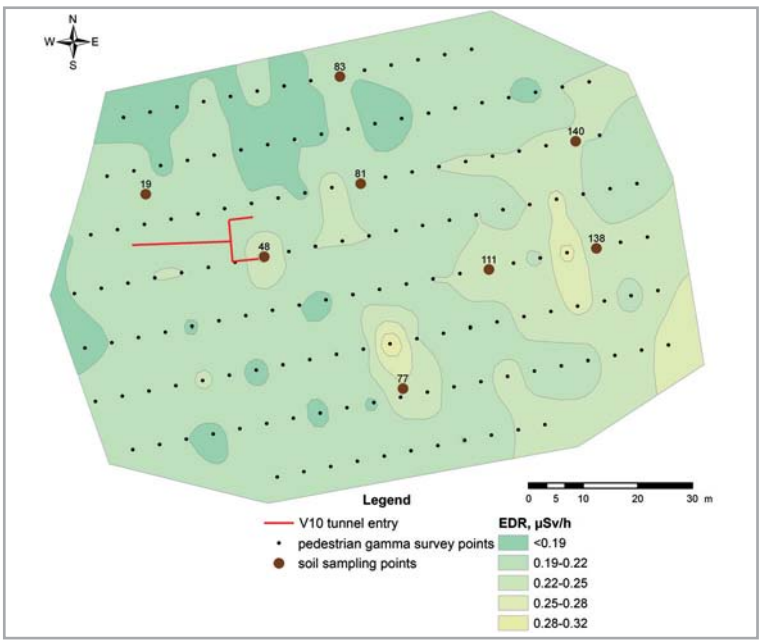


b)

Figure 18. A schematic map of distribution of the density of β-particles flux on the territory of the near portal area of tunnel V9 during preliminary (a) and final (b) inspections

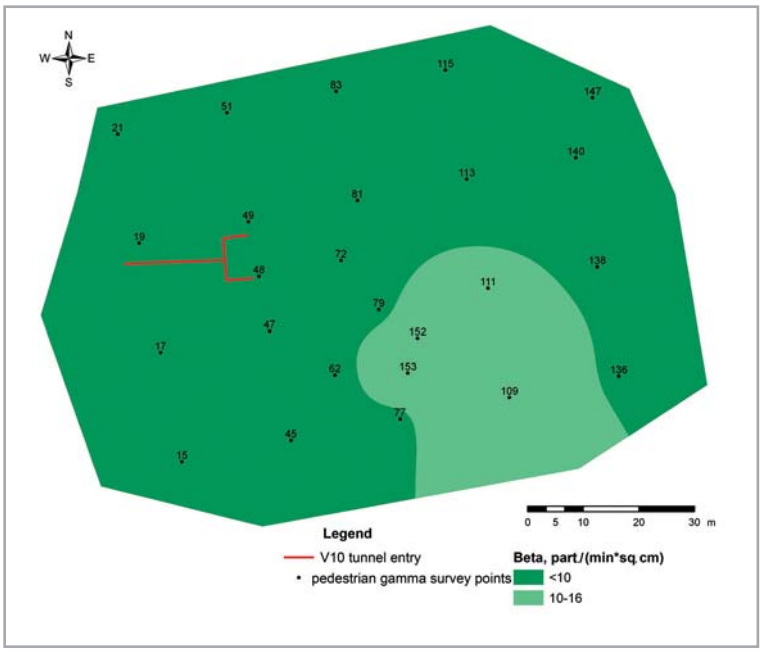


a)

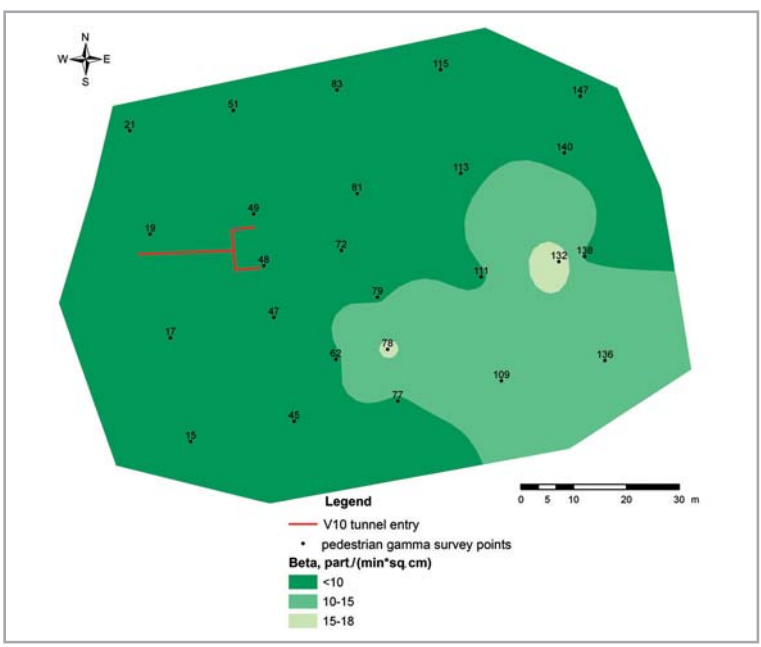


b)

Figure 19. Schematic maps of EDR distribution on the territory of the near portal area of tunnel V10 during preliminary (a) and final (b) inspections

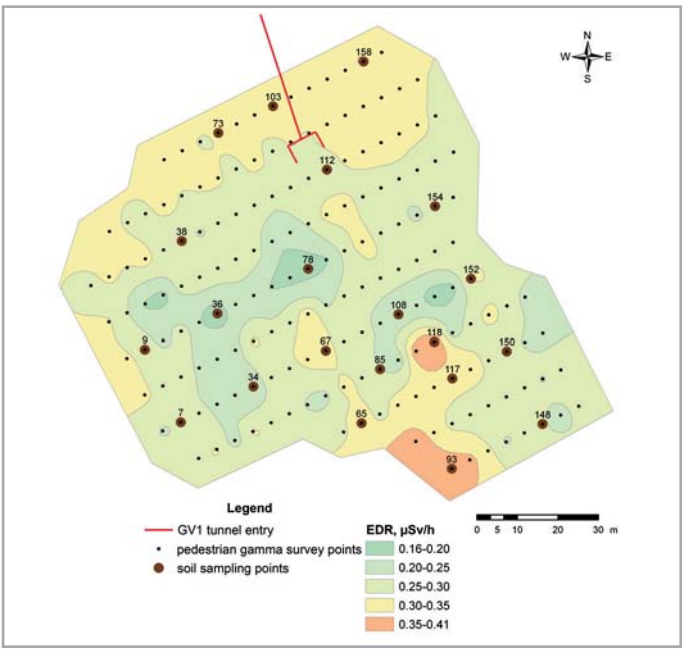


a)

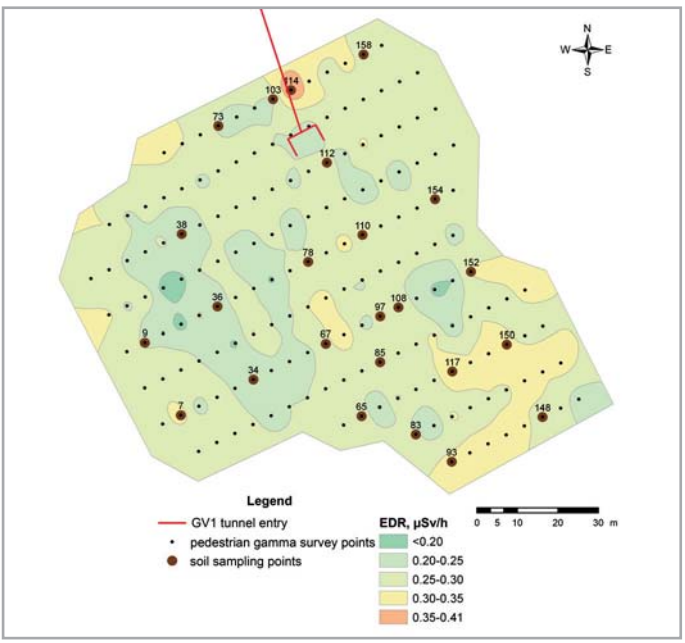


b)

Figure 20. A schematic map of distribution of the density of β-particles flux on the territory of the near portal area of tunnel V10 during preliminary (a) and final (b) inspections

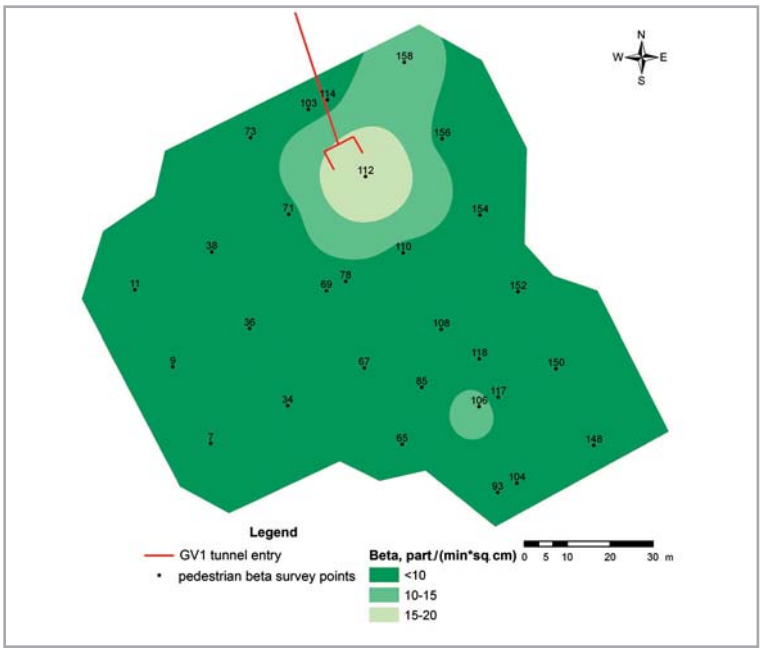


a)

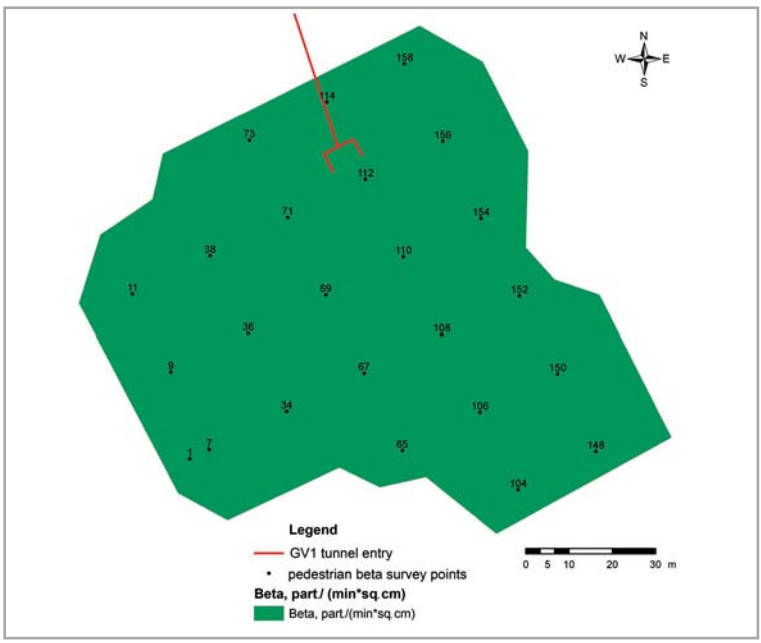


b)

Figure 21. Schematic maps of EDR distribution on the territory of the near portal area of tunnel GV1 during preliminary (a) and final (b) inspections



a)



b)

Figure 22. A schematic map of distribution of the density of β-particles flux on the territory of the near portal area of tunnel GV1 during preliminary (a) and final (b) inspections

Comparison of the 1999 results with the results of the inspection before the works revealed a general tendency to the reduction in the radiation parameters on the territories of the near-portal areas of tunnels. On the territories of tunnels G6, V6, V7, V9, V10 and GV1 a decrease in the maximal values of EDR and density of α- and β-particles fluxes was registered. It may be caused by redistribution of dose-forming artificial radionuclides on the area. However, one should not exclude that different methods of field investigations in different periods of time were used (different devices, different precisions, a human factor), what could give different initial data. In tunnels G5 and V8 increased values of radiological parameters (in G5 an increase in the density of β-particles flux from 21 to 220 part/(min·cm^2), in V8 an increase in EDR from 0.44 to 1 μSv/h) were registered. An increase in the values of the radiation parameters on the territory of the near portal areas may be explained either by unauthorized activities [1] or by the methods of measurements in 1999, which used only a mesh without more precise determination of maximal contamination in "Search" regime.

4.2. Radionuclide contamination of the surface soil layer

In order to obtain a preliminary estimation of radionuclide contamination of the studied areas, soil samples gathered during preliminary examination of near-portal tunnel areas were analyzed by spectrometric and radiochemical methods.

Concentrations of natural radionuclides on the studied territory of the tunnels at the mountain massif correspond to the natural background of the region (mainly, granite rocks). For artificial radionuclides the following specific activities were taken as background values: ^{137}Cs – 30 Bq/kg, ^{90}Sr – 20 Bq/kg, ^{241}Am – 0.2 Bq/kg and $^{239+240}$Pu – 1 Bq/kg. In order to determine the hazard level of an object, the laboratory data on concentrations of artificial radionuclides in soil were compared with the minimal significant specific activity according to NRB-99: ^{137}Cs – $1\cdot10^4$ Bq/kg, ^{90}Sr –$1\cdot10^5$ Bq/kg, ^{241}Am – $1\cdot10^3$ Bq/kg, $^{239+240}$Pu – $1\cdot10^3$ Bq/kg.

The maximal values of specific activity of radionuclides ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu for the period of preliminary inspection of the tunnels are presented in the table (Table 3) and the histogram (Figure 23) below.

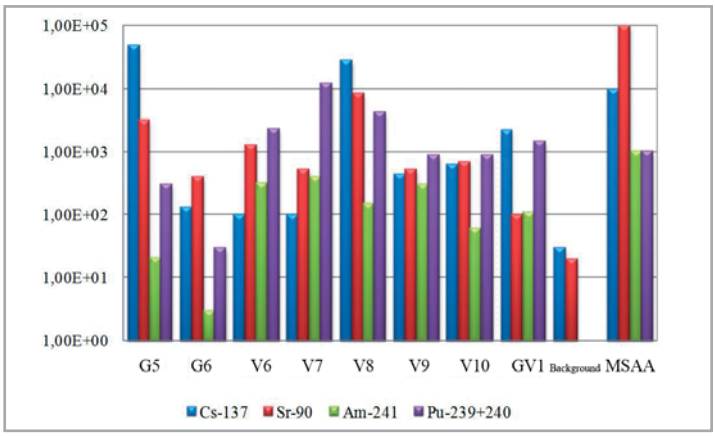


Figure 23. Maximal values of radionuclides specific activity for the period of preliminary inspection of the tunnels, Bq/kg

Concentration of $^{239+240}$Pu in 20% of the sampling points was determined by radiochemical analysis; then for each tunnel the average ratio of ^{241}Am to $^{239+240}$Pu was determined, which was used to calculate the expected $^{239+240}$Pu concentration in soil.

Maximal concentration of ^{90}Sr and ^{241}Am on the territory of inspected tunnels did not exceed minimal significant specific activity (MSSA) for these radionuclides – $1 \cdot 10^5$ and $1 \cdot 10^3$ Bq/kg.

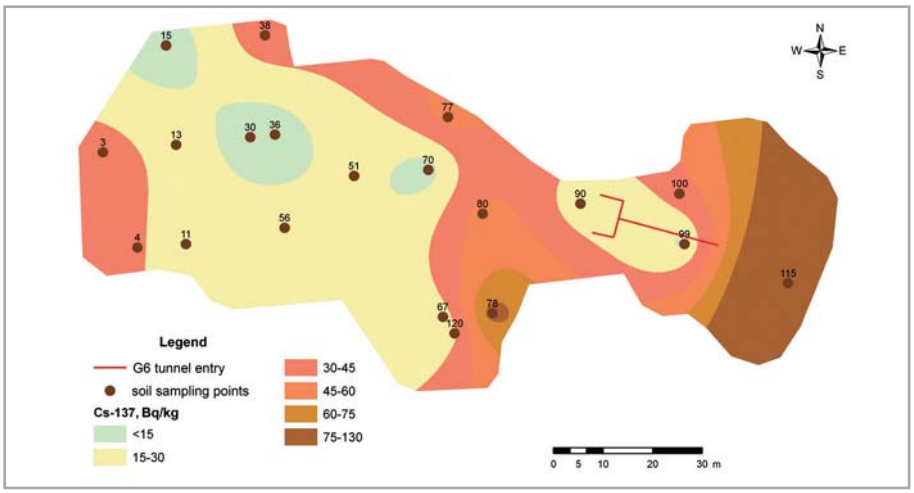
Based on the results of comparison of maximal values of specific activities of radionuclides ^{137}Cs, ^{241}Am and $^{239+240}$Pu with the normative level (MSSA, NRB-99), the tunnels were subdivided by the character of contamination:

1. Tunnels on the studied areas of which concentration of radionuclides in soil did not exceed the normative level for all determined radionuclides (G6, V9, V10);
2. Tunnels on the studied areas of which maximal concentration of ^{137}Cs and/or $^{239+240}$Pu in soil did not exceed the MSSA level (G5, V6, V7, V8, GV1).

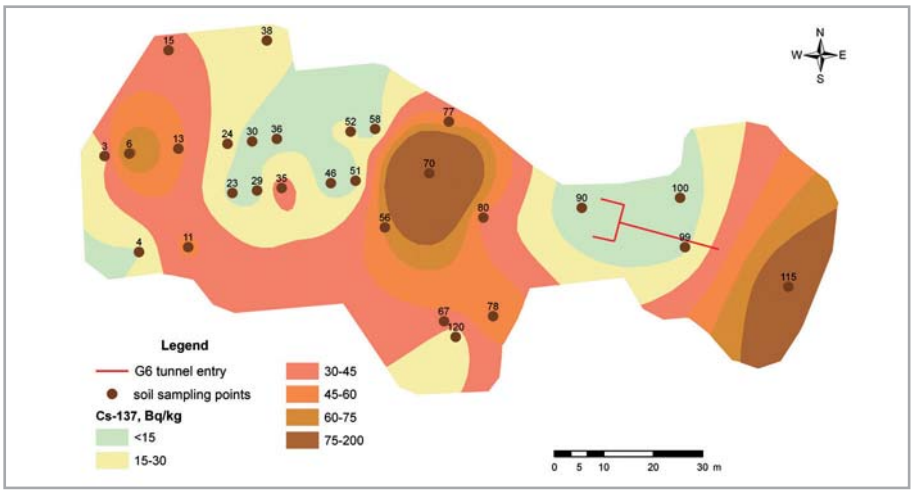
The first group of tunnels was radiation-safe. The concentration of ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu in the soil of the studied area of tunnels G6, V9, V10 did not exceed the normative level (MSSA, NRB-99) equal to $1 \cdot 10^4$, $1 \cdot 10^5$, $1 \cdot 10^3$ and $1 \cdot 10^3$ Bq/kg, respectively (Figure 24a – Figure 26 a). At the preliminary stage, maximal concentration of ^{137}Cs in the studied objects had the values $6.4 \cdot 10^2$ Bq/kg, ^{90}Sr – $7.0 \cdot 10^2$ Bq/kg (tunnel V10), ^{241}Am – $3.0 \cdot 10^2$ Bq/kg (tunnel V9), $^{239+240}$Pu – $9.0 \cdot 10^2$ Bq/kg (tunnels V9 and V10).

The second group of the tunnels (G5, V6, V7, V8, GV1) is characterized by the exceeding MSSA values of 137Cs and/or 239+240Pu concentrations in soil. On the territory of objects V6, V7 and GV1, concentrations exceeding MSSA were registered only for $^{239+240}$Pu (2.3·103, 1.2·104 and 1.5·103 Bq/kg, respectively).

The preliminary inspection of tunnel G5 showed that concentrations of ^{241}Am, ^{90}Sr and ^{137}Cs did not exceed the normative level, accepted according to NRB-99, except for the point 140, where the ^{137}Cs specific activity was as high as $5 \cdot 10^4$ Bq/kg (Figure 30 a – 31 a). Because of high ^{137}Cs concentration in the point, it was difficult to determine the ^{241}Am concentration there, which gave a low limit of equipment sensitivity for this radionuclide (<10). In the point of maximal concentration of ^{241}Am (point 131), the $^{239+240}$Pu concentration determined by radiochemical analysis was 90 Bq/kg. This fact shows that no values of $^{239+240}$Pu concentration exceeding the normative level were detected on the studied area.

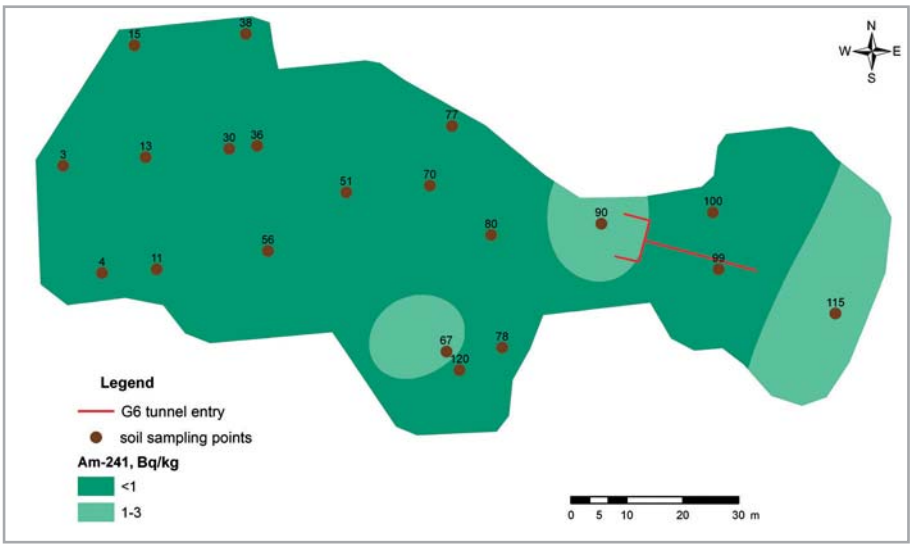


a)

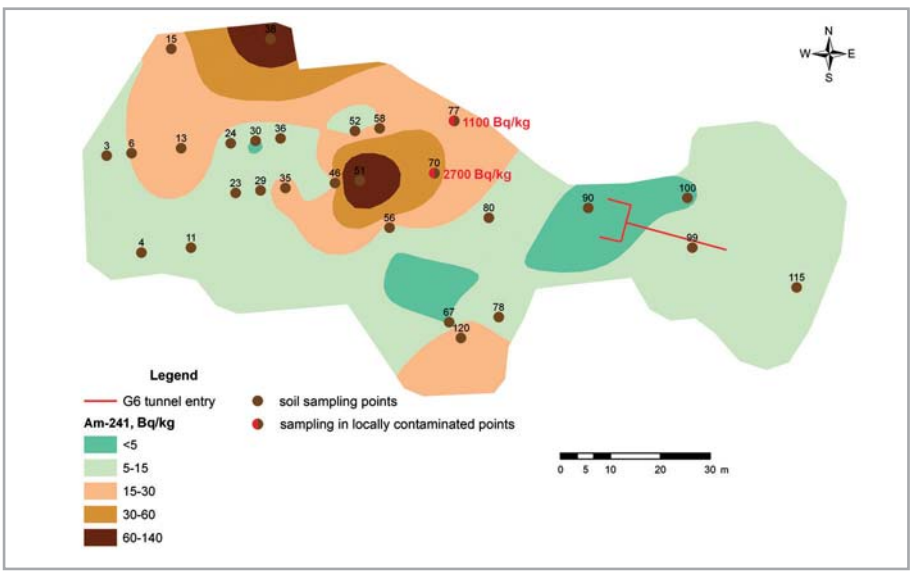


b)

Figure 24. Schematic maps of ^{137}Cs distribution on the territory of the near portal area of tunnel G6 during preliminary (a) and final (b) inspections

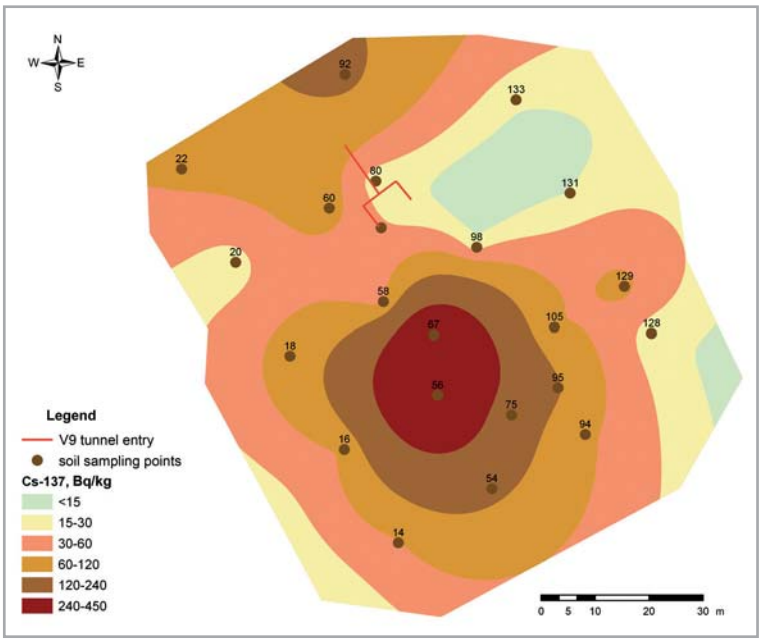


a)

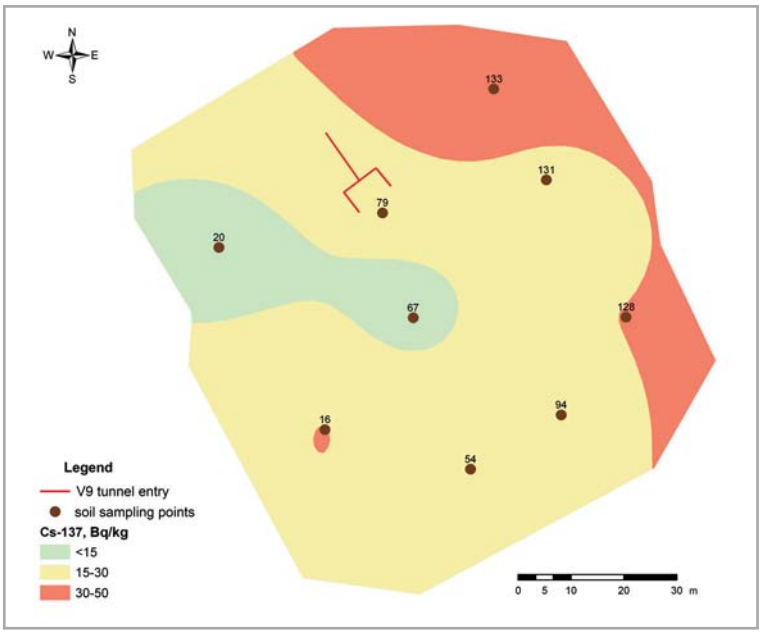


b)

Figure 25. Schematic maps of ^{241}Am distribution on the territory of the near portal area of tunnel G6 during preliminary (a) and final (b) inspections

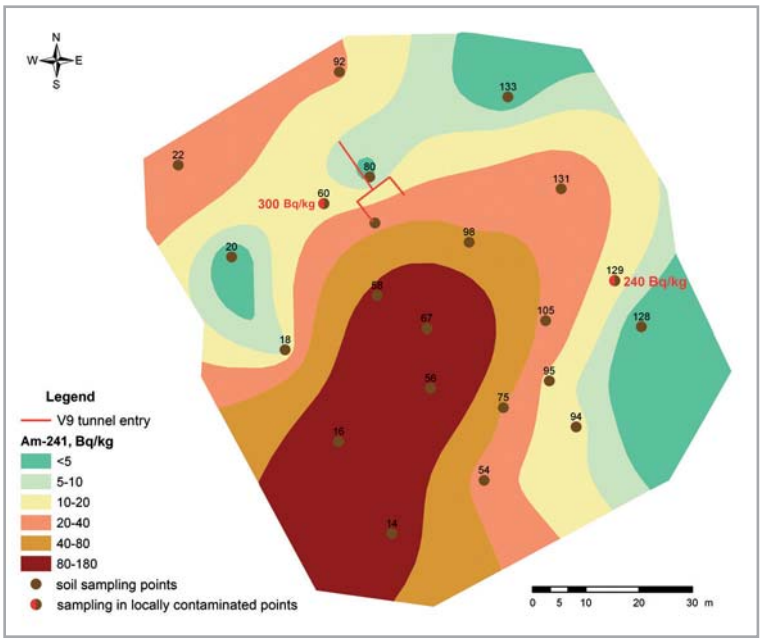


a)

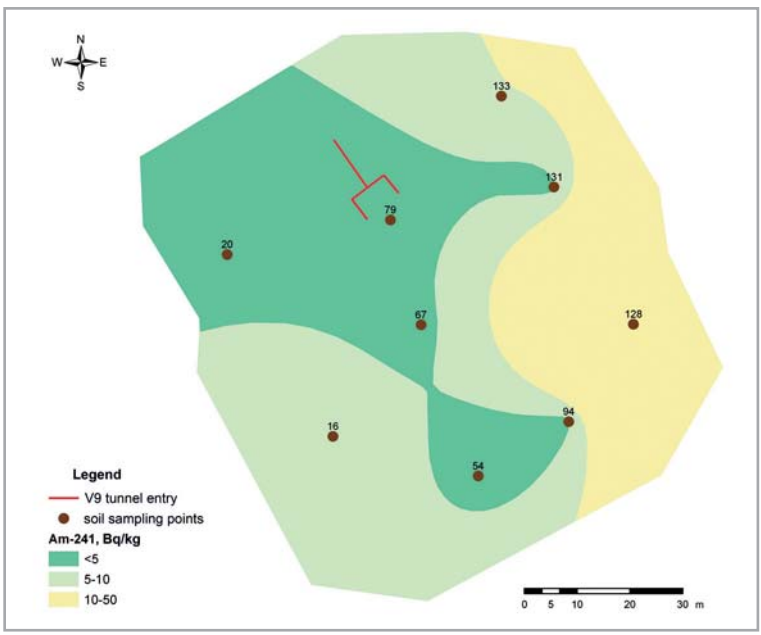


b)

Figure 26. Schematic maps of ^{137}Cs distribution on the territory of the near portal area of tunnel V9 during preliminary (a) and final (b) inspections

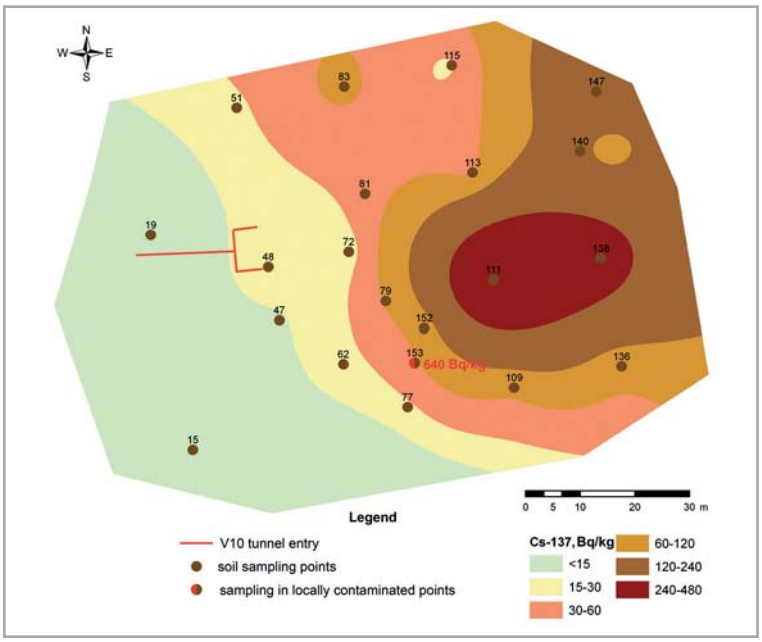


a)

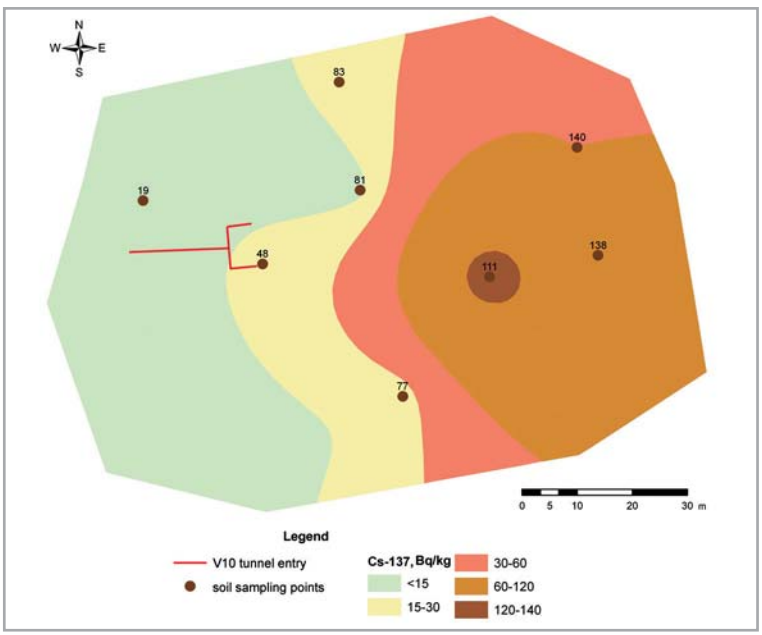


b)

Figure 27. Schematic maps of ^{241}Am distribution on the territory of the near portal area of tunnel V9 during preliminary (a) and final (b) inspections

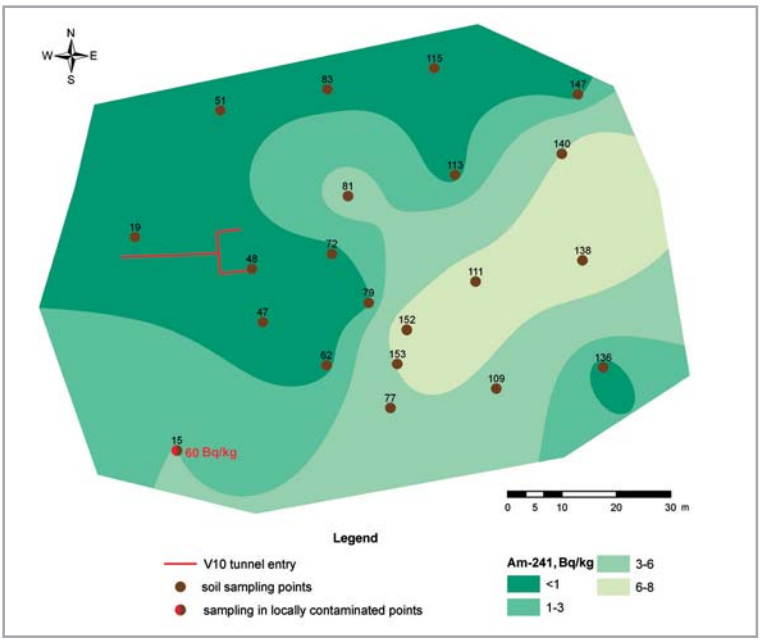


a)

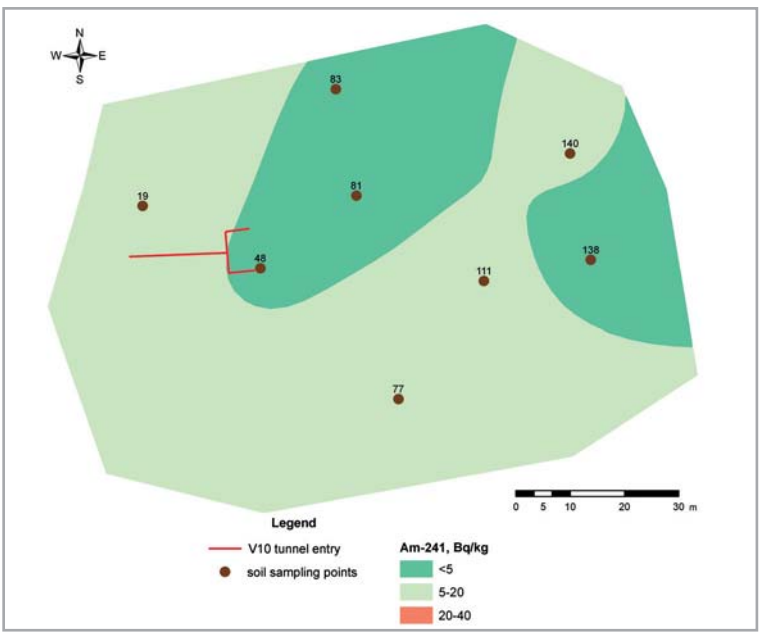


b)

Figure 28. Schematic maps of ^{137}Cs distribution on the territory of the near portal area of tunnel V10 during preliminary (a) and final (b) inspections

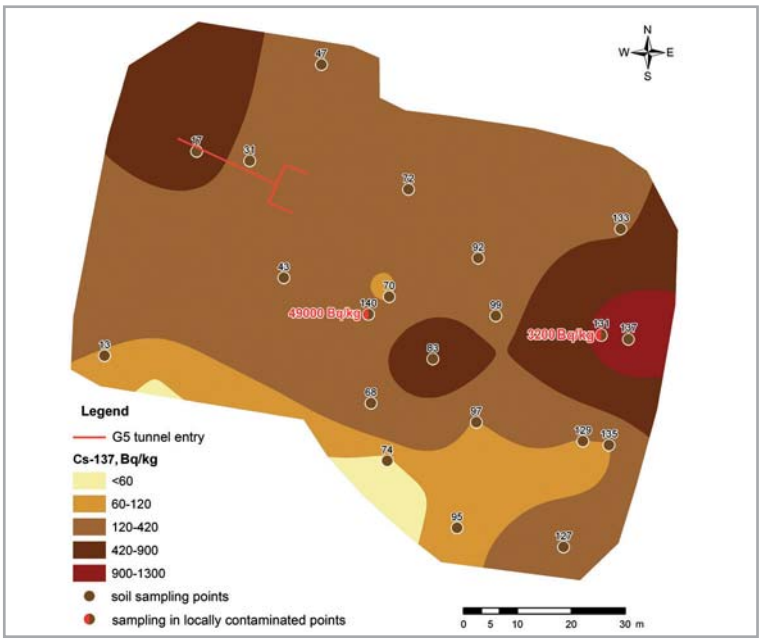


a)

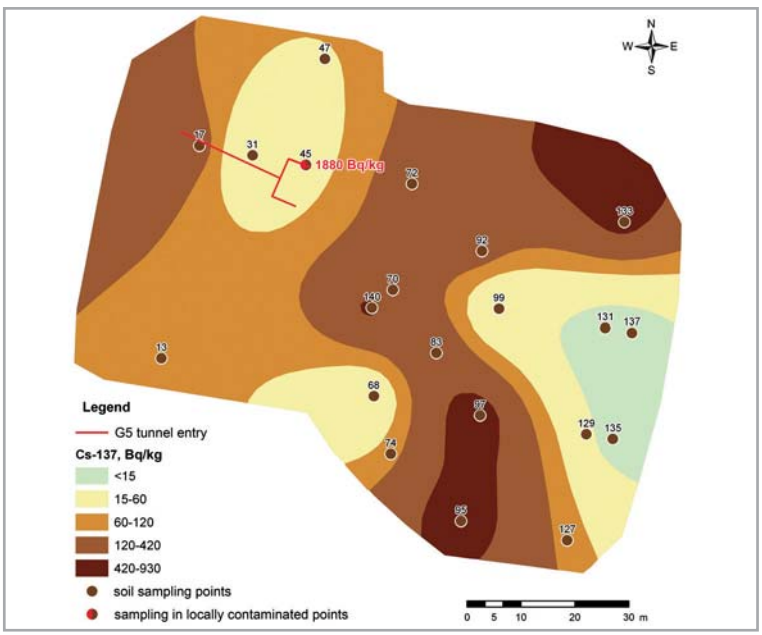


b)

Figure 29. Schematic maps of ^{241}Am distribution on the territory of the near portal area of tunnel V10 during preliminary (a) and final (b) inspections

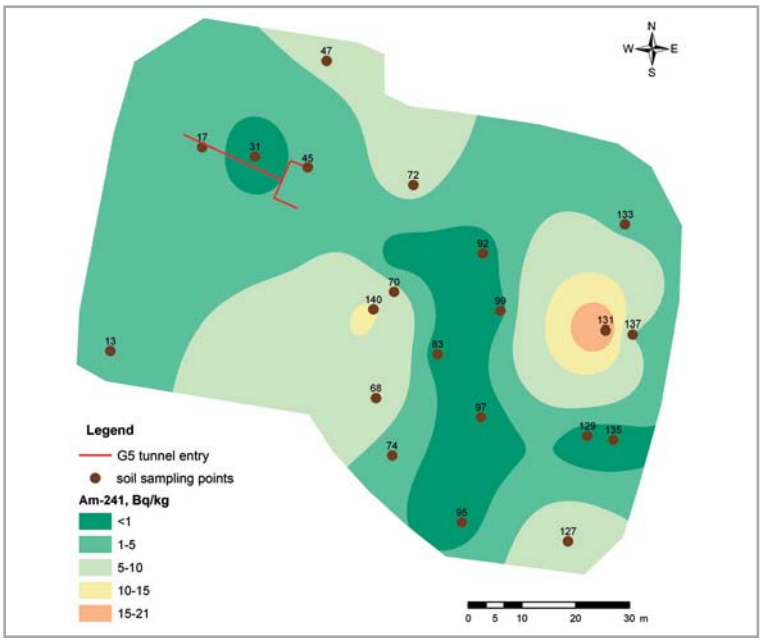


a)

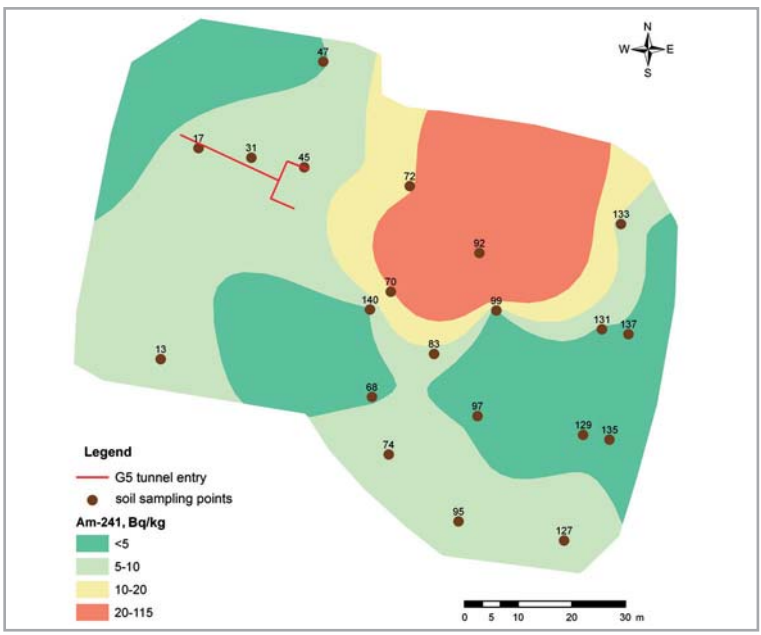


b)

Figure 30. Schematic maps of ^{137}Cs distribution on the territory of the near-portal area of tunnel G5 during preliminary (a) and final (b) inspection



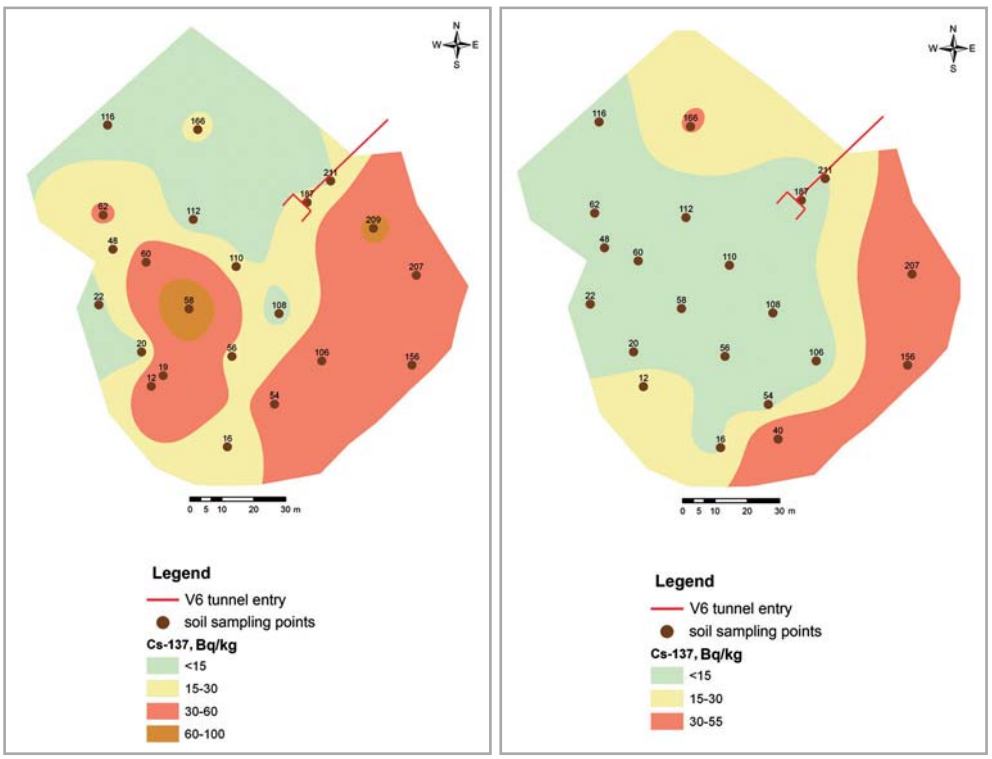
a)



b)

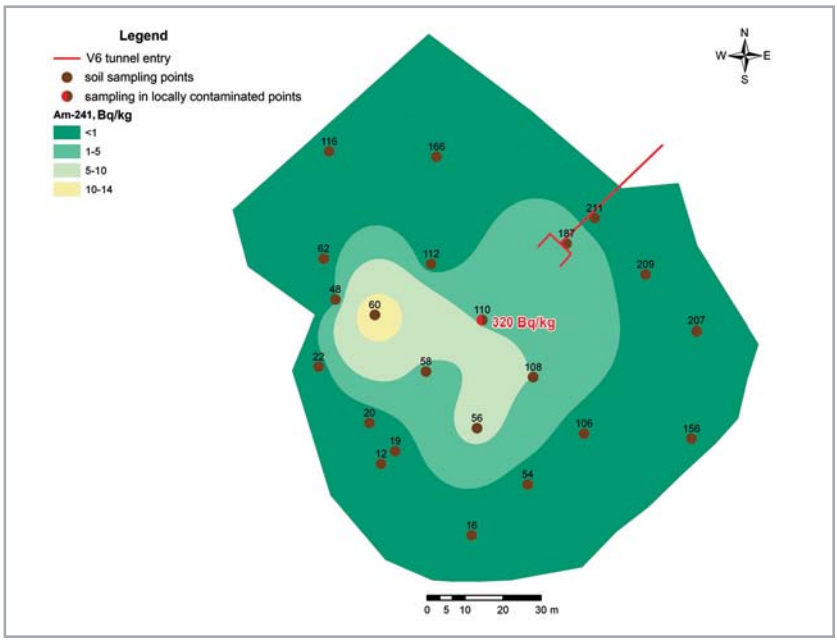
Figure 31. Schematic maps of ^{241}Am distribution on the territory of the near-portal area of tunnel G5 during preliminary (a) and final (b) inspections

The laboratory analyses of soil samples from the tunnel V6 (Figure 32 a – 33 a) showed the presence of local contamination by the artificial radionuclide $^{239+240}$Pu on the area of point 110. The specific activity of $^{239+240}$Pu in the point exceeded the MSSA level by a factor of 2.3. The level of contamination of the area by ^{137}Cs and ^{90}Sr did not exceed normative levels. The obtained data confirmed the assumption about an "incomplete" nuclear explosion in the tunnel, which is characterized by low activity of fission products (^{137}Cs and ^{90}Sr) and rather high specific activity of fissionable material ($^{239+240}$Pu). The analysis of the soil from point 209 showed an anomalously high concentration of natural Th, as compared with other studied points, the specific activity of which 2.4 times exceeded MSSA for this radionuclide. This point also had an increased, as compared with the other points, concentration of ^{90}Sr ($1.3 \cdot 10^3$ Bq/kg). The presence of these radionuclides in the soil sample could cause an increase in the detection threshold in registration of ^{241}Am.

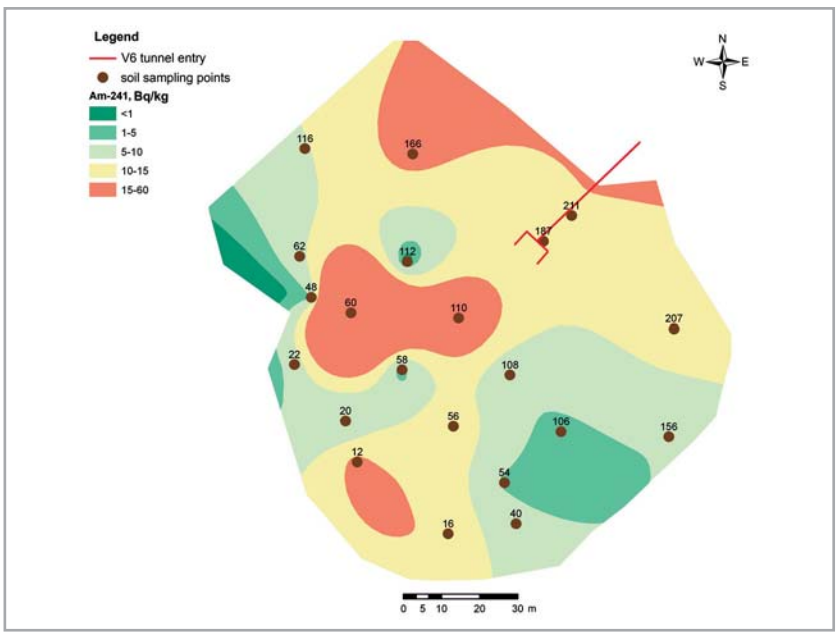


a) b)

Figure 32. Schematic maps of ^{137}Cs distribution on the territory of the near-portal area of tunnel V6 during preliminary (a) and final (b) inspections



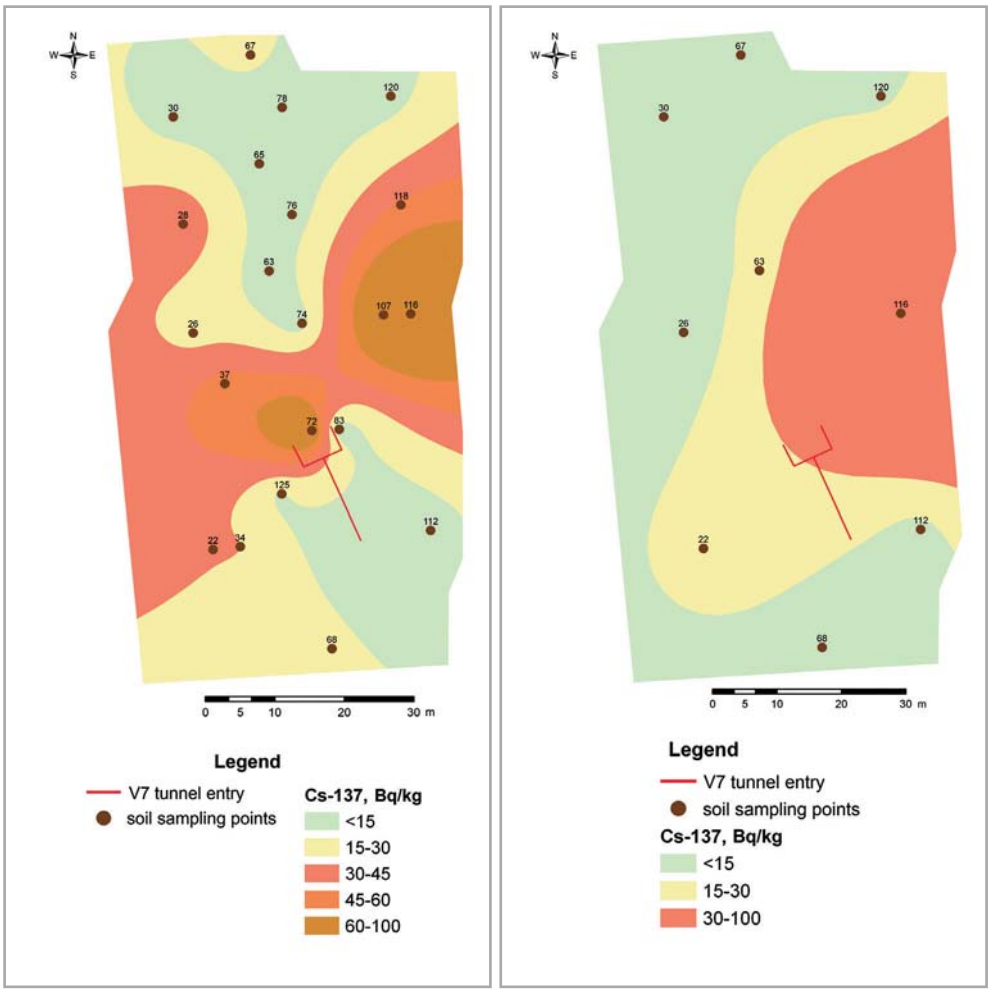
a)



b)

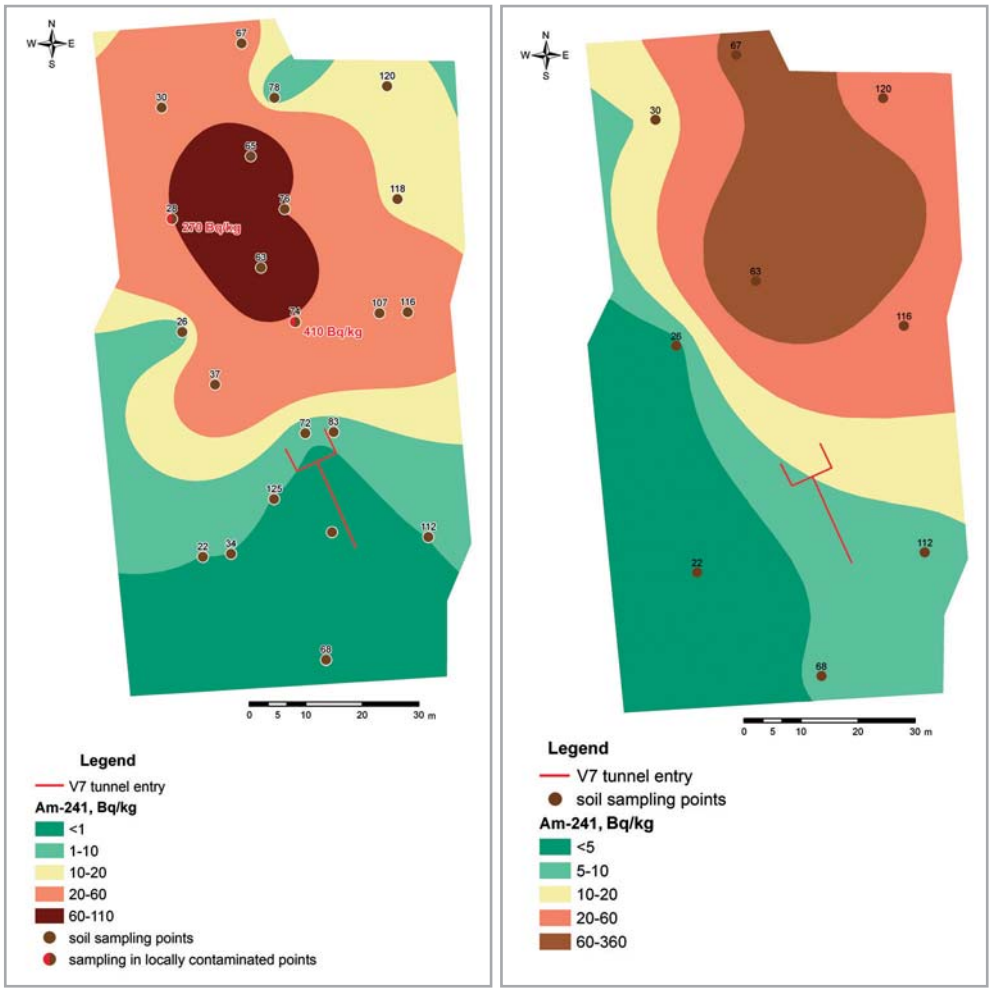
Figure 33. Schematic maps of ^{241}Am distribution on the territory of the near-portal area of tunnel V6 during preliminary (a) and final (b) inspections

On the territory of the near-portal area V7, maximal concentration of ^{241}Am in soil was 410 Bq/kg, as a result the specific activity of $^{239+240}$Pu could exceed the MSSA normative level. Concentrations of ^{90}Sr and ^{137}Cs did not exceed the normative levels accepted according to NRB-99 (Figures 34a-35a).



a) b

Figure 34. Schematic maps of ^{137}Cs distribution on the territory of the near-portal area of tunnel V7 during preliminary (a) and final (b) inspections

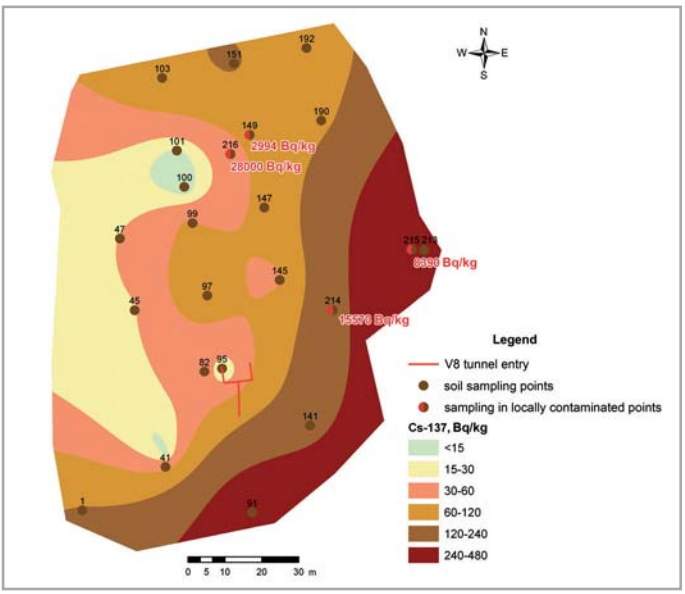


a) b)

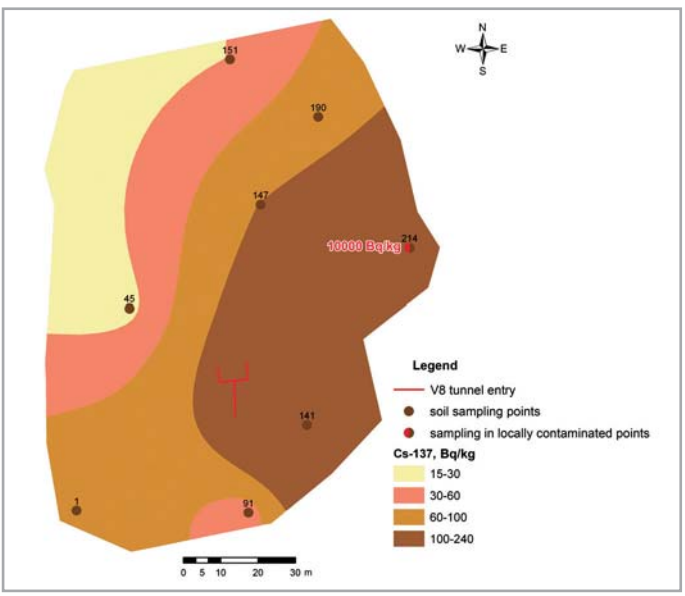
Figure 35. Schematic maps of ^{241}Am distribution on the territory of the near-portal area of tunnel V7 during preliminary (a) and final (b) inspections

Preliminary inspection of tunnel V8 determined the exceeding MSSA values for two artificial radionuclides ^{137}Cs and $^{239+240}$Pu. The concentration of ^{137}Cs in two points exceeded the established level of $1 \cdot 10^4$ Bq/kg (points 214 and 216). In point 215 radionuclides ^{60}Co (22±2 Bq/kg) and ^{152}Eu (33±2 Bq/kg) were detected. In point 216 radionuclides ^{238}U (1600±100 Bq/kg) and ^{235}U (70±20 Bq/kg) were registered. The concentrations of ^{241}Am and ^{90}Sr on the studied area did not exceed normative levels accepted according to NRB-99 ($1 \cdot 10^3$ and $1 \cdot 10^5$ Bq/kg, respectively). In the samples taken for the radiochemical determination of Pu concentration, the radionuclide was detected. However, its amount did not exceed the regulatory level, except for point 214 (by a factor of 4.2). In the other points no excess in

the concentration of $^{239+240}$Pu over the normative level was expected. Schematic maps of ^{137}Cs and ^{241}Am distributions are presented in Figures 36a-37a.

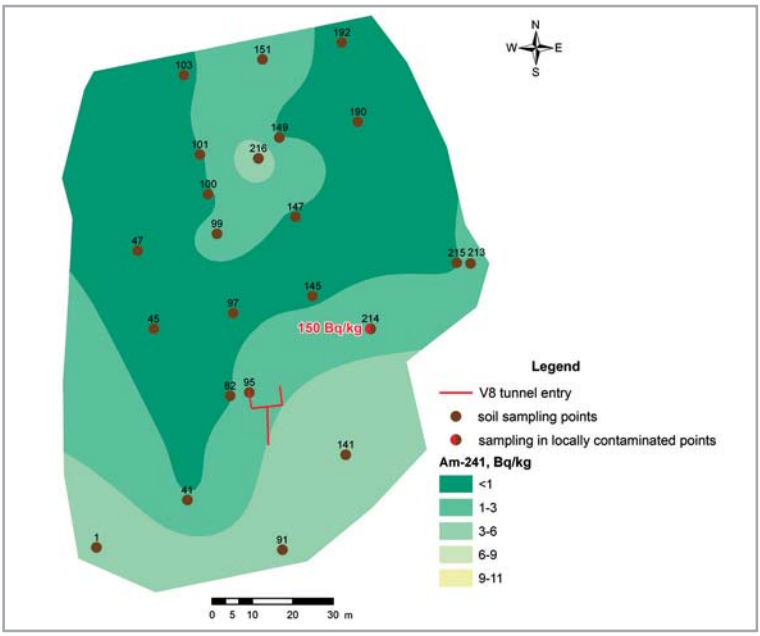


a)

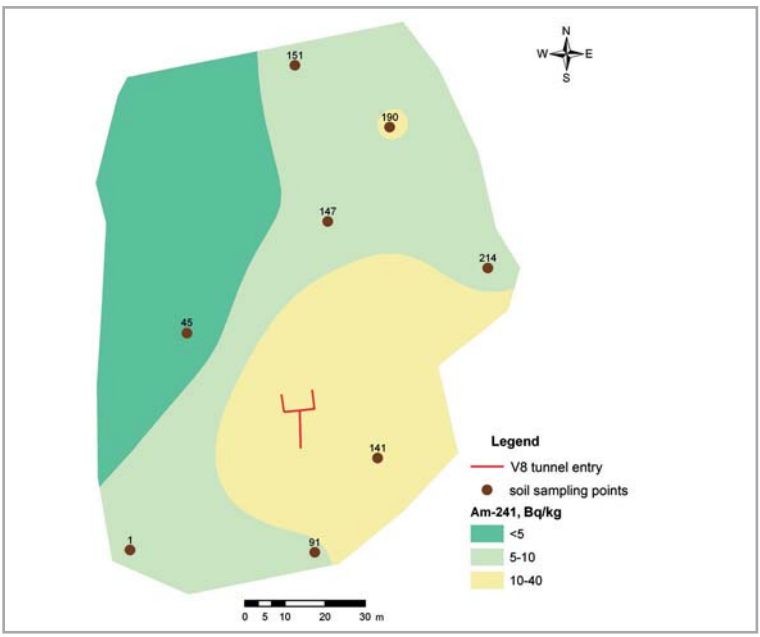


b)

Figure 36. Schematic maps of ^{137}Cs distribution on the territory of the near-portal area of tunnel V8 during preliminary (a) and final (b) inspections



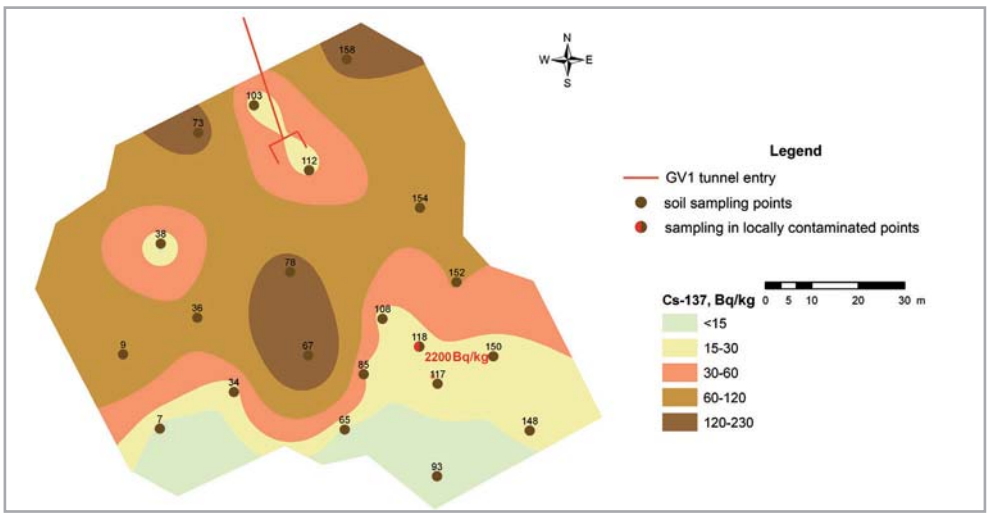
a)



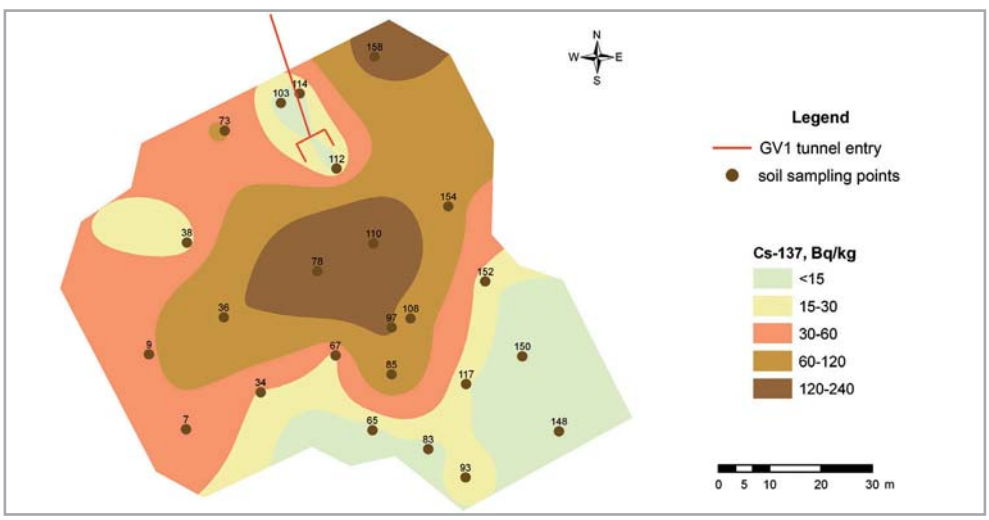
b)

Figure 37. Schematic maps of ^{241}Am distribution on the territory of the near-portal area of tunnel V8 during preliminary (a) and final (b) inspections

Preliminary radioecological survey in the tunnel GV1 showed that practically on all studied territory the radioecological situation could be characterized as satisfactory (Figure 38 a, Figure 39 a). The concentration of $^{239+240}$Pu on the studied area did not exceed $1.7 \cdot 10^2$ Bq/kg, which is 5.8 times lower than MSSA for this radionuclide. However, the laboratory analysis showed that in point 152 the $^{239+240}$Pu concentration was 1.5 times higher than MSSA, which gives grounds to refer this soil to the category of radioactive wastes.

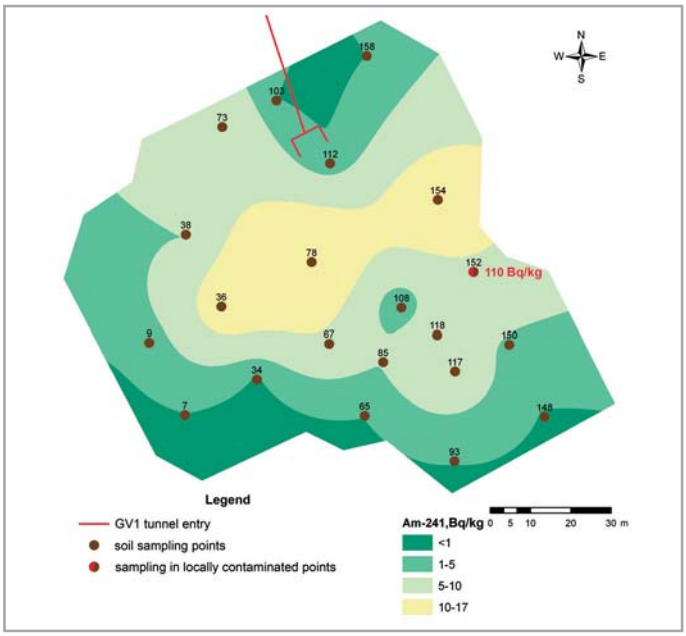


a)

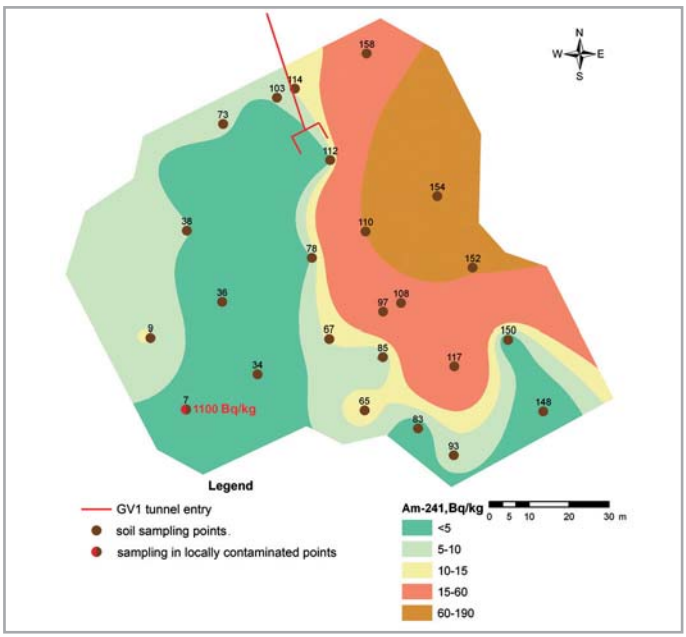


b)

Figure 38. Schematic maps of ^{137}Cs distribution on the territory of the near-portal area of tunnel GV1 during preliminary (a) and final (b) inspections



a)



b)

Figure 39. Schematic maps of ^{241}Am distribution on the territory of the near-portal area of tunnel GV1 during preliminary (a) and final (b) inspections

Comparison of the data of preliminary inspection with the 1999 data showed that maximal values of specific activities of artificial radionuclides could vary widely. Thus, maximal specific activity of ^{137}Cs is now $4.9 \cdot 10^4$ Bq/kg ($5.8 \cdot 10^4$ Bq/kg in 1999), ^{90}Sr – $8.7 \cdot 10^3$ Bq/kg ($1.3 \cdot 10^3$ Bq/kg in 1999), $^{239+240}$Pu – $1.2 \cdot 10^4$ Bq/kg ($7.5 \cdot 10^2$ Bq/kg in 1999).

As there are no exact data on the conditions and methods of investigations carried out 10 years ago, it is possible to suppose that the 1999 data gave only estimations, and the aim of research was to evaluate the radiation situation on the objects in general without any detailed examination of the territory and detection of locally contaminated areas. Therefore, the preliminary inspection of the territory of the near-portal areas enabled us to obtain more accurate data on the radiation situation in the vicinity of tunnels.

4.3. Radionuclide contamination of the surface atmospheric air

In order to obtain information on radionuclide contamination of the atmospheric air on the studied objects, samples of air aerosols were taken and analyzed. The results of laboratory analyses are presented in the table (Table 3).

The laboratory analyses did not reveal any gamma-emitting artificial radionuclides in the samples of air aerosols. An analysis of the obtained data showed that concentration of the main dose-forming radionuclides ^{241}Am and ^{137}Cs in the atmospheric air on the studied objects was below the detection limit of used measuring equipment.

4.4. Conclusions from the preliminary inspection of the near-portal tunnel areas

A general tendency to the reduction in the values of radiation parameters on the territories of the near-portal areas of tunnels (by the results of the 1999 survey and the pre-work inspection) may be caused by the redistribution of dose-forming artificial radionuclides on the area and use of different methods of field investigations in different periods of time (different devices, different precisions, a human factor). In tunnels G5 and V8 increased values of radiation parameters were registered, which may be caused either by unauthorized activities [1] or the methods of measurements in 1999, which used only a mesh without more precise determination of maximal contamination in "Search" regime.

In the preliminary inspection maximal values of specific activities of radionuclides were registered in locally contaminated areas in tunnels G5 (^{137}Cs – $4.9 \cdot 10^4$ Bq/kg), V8 (^{90}Sr – $8.7 \cdot 10^3$ Bq/kg), V7 (^{241}Am – $4.1 \cdot 10^2$ Bq/kg, $^{239+240}$Pu – $1.2 \cdot 10^4$ Bq/kg). Maximal values of specific activities of ^{137}Cs and $^{239+240}$Pu exceeded MSSA normative levels. The values exceeding MSSA for ^{137}Cs were registered in the near-portal areas in 2 tunnels, for $^{239+240}$Pu – in 4 tunnels.

The concentration of artificial radionuclides ^{137}Cs and ^{241}Am in the atmospheric air at the studied objects was below the detection limits of used measuring instruments.

5. RADIOLOGICAL SITUATION AT THE TERRITORY OF NEAR-PORTAL TUNNEL AREAS AFTER COMPLETION OF CONSERVATION WORKS

5.1. Radiation situation by the results of radiometric and dosimetric measurements

Using the results of final inspection, schematic maps of distributions of radiation parameters on the studied areas were constructed (Figures 7b-22b).

Maximal and minimal measured EDR values in the period of final inspection are presented in the histogram (Figure 40).

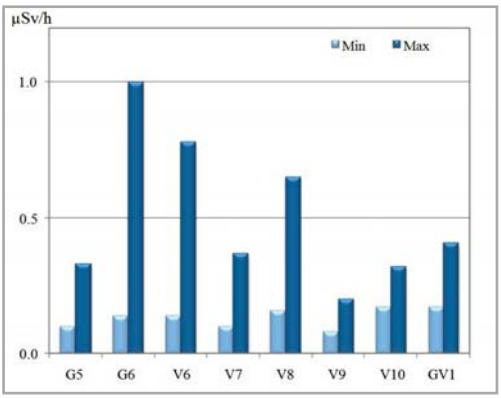


Figure 40. Maximal and minimal measured EDR values on the territory of the near-portal areas after completion of conservation works

Minimal values of the β-flux density registered during final inspection at the near-portal territories did not exceed 10 part/(min·cm^2) for all the tunnels. Maximal values of the β-flux density registered during final inspection are presented in the histogram (Figure 41).

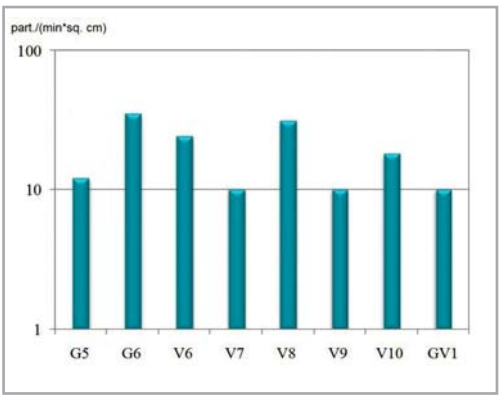


Figure 41. Maximal values of the β-flux density after completion of conservation works

The values of density of the flux of α-particles registered during final inspection in all studied areas did not exceed the detection limit of used measuring instruments (0.2-1 part/(min·cm^2)).

According to the final inspection of the tunnels, maximal values of the radiological parameters were registered on the territory of the near-portal areas of tunnels G6 (EDR – 1.02 μSv/h) (Figure 9 a), V6 (EDR – 0.78 μSv/h)) (Figure 11 b) and V8 (EDR – 0.65 μSv/h), (Figure 15 b). The results of inspection showed that on the territory of all tunnels radiation parameters did not exceed maximal permissible values for personnel of A category [5].

5.2. Radionuclide contamination of the surface soil layer

By the results of the final inspection of the near-portal tunnel areas after completion of the conservation works, residual contamination of the territory of the near-portal areas was estimated and schematic maps of distributions of ^{137}Cs and ^{241}Am were made (Figure 26 b, Figure 37 b). Maximal values of specific activities for radionuclides ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu registered during final inspection of the tunnels are presented in the table (Table 3) and in the histogram (Figure 42).

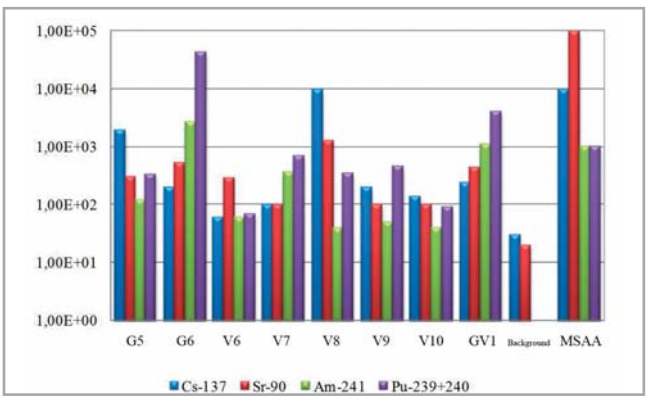


Figure 42. Maximal values of the radionuclides specific activities during final inspection of the tunnels, Bq/kg

Maximal concentration of ^{90}Sr in the studied tunnels did not exceed MSSA ($1 \cdot 10^5$ Bq/kg) for this radionuclide.

Comparing maximal values of specific activities for ^{137}Cs, ^{241}Am and $^{239+240}$Pu with the regulatory levels (MSSA, NRB-99), the near-portal areas of the tunnels were subdivided by the character of contamination into the following 3 groups:

1. Tunnels at the studied areas with concentration of the radionuclides in soil did not exceed the regulatory level for all determined radionuclides (G5, V6, V7, V9, V10);
2. The tunnel in which maximal concentration of ^{137}Cs was at the MSSA level (V8);
3. Tunnels in the studied areas with maximal specific activities of transuranium radionuclides ^{241}Am and $^{239+240}$Pu exceeding MSSA for these radionuclides (G6, GV1).

The first group of tunnels according to MSSA values was radiation-safe. At the final stage, the following maximal values of the radionuclide concentrations on the territory of the near-portal areas were registered: ^{137}Cs – $1.9 \cdot 10^3$ Bq/kg, ^{90}Sr – $3.0 \cdot 10^2$ Bq/kg,^{241}Am – $3.6 \cdot 10^2$ Bq/kg, $^{239+240}$Pu – $7.0 \cdot 10^2$ Bq/kg (tunnel V7).

According to the character of contamination, tunnel V8 is to be put in a special group. In the examination of the near-portal area of tunnel V8, a local contamination (point 214, Figure 36 b) with decreased background of natural radionuclides was detected, which is most likely caused by dilution of the natural soil by man-made remnants produced as a result of unauthorized burning of cables and other details from the tunnel. It gave increased concentration of artificial radionuclides in the point. The specific activity of ^{137}Cs registered in the tunnel was $1.0 \cdot 10^4$ Bq/kg, which was equal to MSSA for this radionuclide. Maximal concentration of $^{239+240}$Pu equal to 350 Bq/kg was registered in point 141, concentrations of ^{241}Am and ^{90}Sr did not exceed normative levels. There were also detected radionuclides ^{60}Co, ^{152}Eu and ^{154}Eu in amounts of 80, 150 and 70 Bq/kg, respectively.

The third group of tunnels is characterized by an increased MSSA for the concentration of transuranium radionuclides ^{241}Am and $^{239+240}$Pu in soil of the studied area. Maximal value of specific activity registered for ^{241}Am was $2.7 \cdot 10^3$ Bq/kg, for $^{239+240}$Pu – $4.3 \cdot 10^4$ Bq/kg (tunnel G6).

In the near-portal area of tunnel GV1 the maximal value of ^{241}Am specific activity equal to $1.1 \cdot 10^3$ Bq/kg, which is 1.1 times higher than the MSSA, was registered in point 7. The $^{239+240}$Pu specific activity in the point was equal to $4.1 \cdot 10^3$ Bq/kg. The values of $^{239+240}$Pu specific activity exceeding the normative level were observed in 20 % of examined points in the near-portal area. The ^{137}Cs concentration in the tunnel varied from 7 to 240 Bq/kg, the ^{90}Sr specific activity did not exceed 450 Bq/kg.

In the final inspection of the near-portal area of tunnel G6, ^{241}Am was only registered in amounts not exceeding MSSA, except for two points 70 and 77 ($2.7 \cdot 10^3$ and $1.1 \cdot 10^3$ Bq/kg) located opposite the tunnel portal on the working area. The laboratory and calculated data showed that an excess in the $^{239+240}$Pu concentration over the normative MSSA level could be also registered only in points 70 and 77. Maximal value of specific activity could be as high as $4.3 \cdot 10^4$ Bq/kg. In point 35 the concentration of plutonium isotopes was at the MSSA level – $9.8 \cdot 10^2$ Bq/kg, therefore taking into account analytical errors, the soil in the point could be referred to the category of radioactive wastes.

Specific activities of ^{137}Cs and ^{90}Sr in the soil of tunnel G6 did not exceed the values of minimally significant activity for these radionuclides, but by the concentration of ^{241}Am and $^{239+240}$Pu the near-portal area was the most radiation-hazardous area of all compared 8 tunnels.

5.3. Radionuclide contamination of the surface atmospheric air

In the final inspection of the near-portal tunnel areas it was not necessary to determine the contamination of the surface atmospheric layer as the preliminary inspection did not register any significant values of volumetric activity of radionuclides in air even in case of very high concentrations of radionuclides in soil.

5.4. Conclusions of the final inspection of the near-portal tunnel areas

The final inspection showed that maximal values of radiation parameters were registered on the territory of the near-portal areas of tunnels G6, V6 and V8. The results of inspection after completion of construction of additional protection showed that on the territory of all tunnels radiation parameters did not exceed maximal permissible values for the A category personnel [5].

Laboratory analysis showed that maximal contamination with artificial radionuclides was registered on the near-portal area of tunnel G6. Maximal values of specific activities of radionuclides ^{241}Am and $^{239+240}$Pu were $2.7 \cdot 10^3$ and $4.3 \cdot 10^4$ Bq/kg, respectively. Maximal concentrations of ^{137}Cs and ^{90}Sr were registered in tunnel V8 ($1.0 \cdot 10^4$ Bq/kg).

As a whole, only in 3 near-portal areas, out of 8 tunnels sealed in 2010, the values exceeding regulatory levels for artificial radionuclides were detected.

6. ASSESSMENT OF IMPACT FROM CONSERVATION WORKS ON THE RADIOLOGICAL SITUATION IN THE NEAR-PORTAL TUNNEL AREAS

6.1. Variations in the radiation situation by the results of radiometric and dosimetric measurements

Maximal EDR values registered in preliminary and final inspections are presented in the histogram (Figure 43).

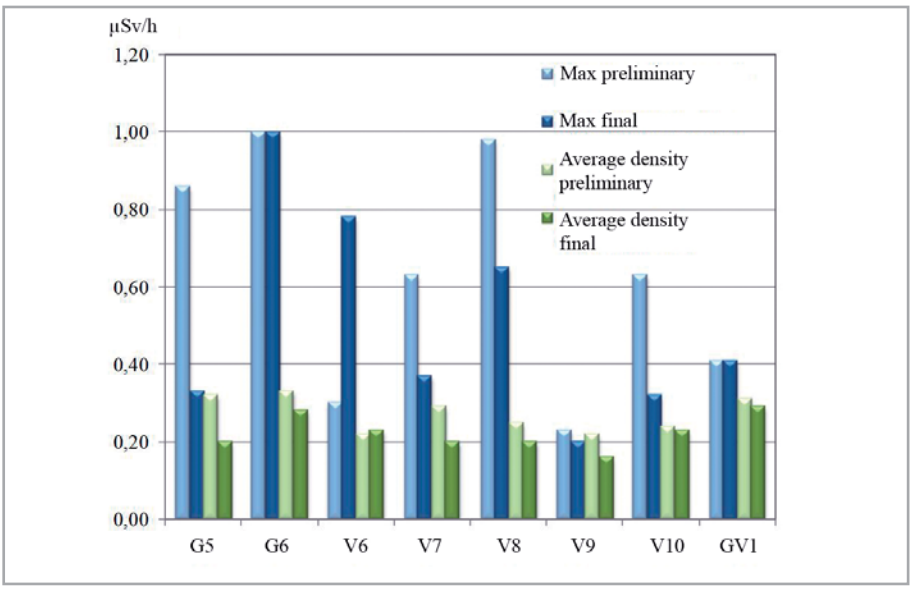


Figure 43. Maximal EDR values and average EDR density registered in the preliminary and final tunnel inspections

The histogram shows that during the preliminary inspection maximal EDR values were detected in the locally-contaminated areas of tunnels G5, G6 and V8 and in the final inspection – in the locally-contaminated areas of tunnels G6 and V6. After works lower maximal EDR values were registered in tunnels G5, V7, V8 and V10. Thus, the initial assessment shows that protection works reduced the levels of radiation contamination on the near-portal areas of the examined tunnels. During the final inspection higher EDR values, as compared with the data of the preliminary inspection, were registered in tunnel V6, which makes it possible to suppose that works on additional protection negatively affected radiation situation in the near-portal areas of that tunnel.

However, maximal EDR values do not fully characterize radiation situation in the near-portal areas as they do not take into account the area of contamination. In order to evaluate the influence of the area of contamination, the average density of contamination was calculated [1]. The results of calculation of the average density of contamination in the near-portal areas based on the data of the preliminary and final inspections are presented in the table and in the histogram (Table 3, Figure 43).

Comparing maximal EDR values before and after conservation works and results of calculation of average contamination densities, it is possible to subdivide the tunnels by the character of radiation situation variation:

1. Tunnels where variations in EDR values and average contamination densities were within the measurement errors of the corresponding quantities (G6, G9, GV1), hence, the protection works did not affect the radiation situation in the near-portal areas;
2. Tunnels where maximal EDR values and average contamination densities decreased (G5, G7), which was a result of decontamination measures before protection works;
3. Tunnels where maximal EDR values decreased whereas the values of average contamination densities remained unchanged within the measurement errors of the corresponding quantity (V8, V10). It is the result of decontamination measures before works, however, it should be noted that before works there were only local areas with maximal EDR values, which did not make any considerable contribution to the average density;
4. Tunnels where maximal EDR values increased and average contamination densities changed insignificantly (within the measurement errors of the corresponding quantity) – V6. The area had local contamination which was caused by carrying-out of contaminated soil and rust during works.

Minimal and maximal values of the β-flux density measured during preliminary and final inspections of the tunnels are presented in the histogram (Figure 44).

Maximal values of the β-flux density were registered during preliminary inspection of the locally-contaminated area of tunnel G5 (220 part/(min·cm^2)). The initial assessment shows that protection works reduced the levels of radiation contamination in the near-portal areas of tunnels G5, V8, GV1 and increased the levels in the near-portal areas of tunnels G6 and V6. On the territories of tunnels V7, V9 and V10 the protection works did not affect the radiation situation.

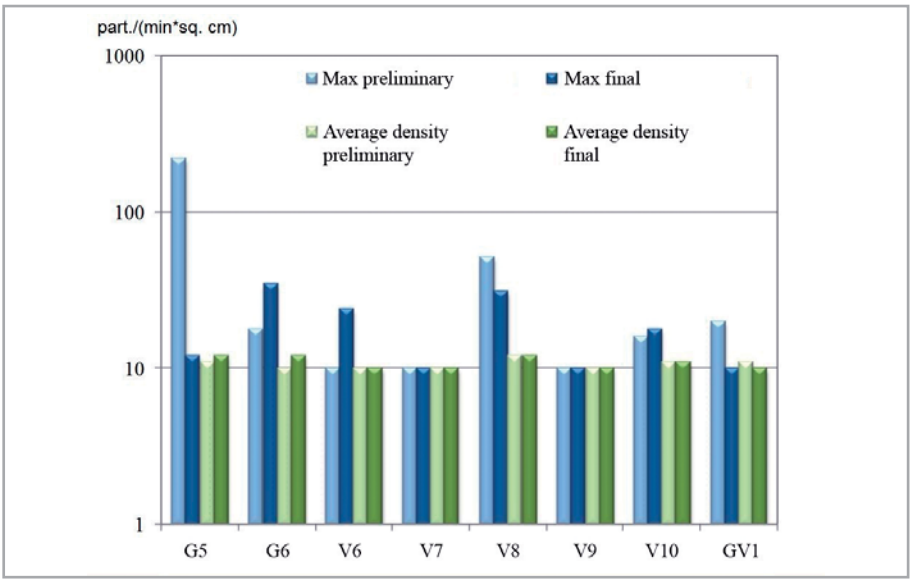


Figure 44. Maximal values and average density of flux of β-particles registered in the preliminary and final tunnel inspections

The average contamination densities for the near-portal areas by the measurements of data of the β-flux density during preliminary and final inspections were calculated (Table 3, Figure 44). The results of calculation of the average density of contamination of the near-portal areas based on the β-flux density showed that the radiation situation did not change after works.

Comparing variations in maximal values of the β-flux density before and after works and results of calculation of average contamination densities, it is possible to subdivide the tunnels by the character of variations in the radiation situation:

1. Tunnels where variations in the β-flux density and average densities were within the measurement errors of the corresponding quantities (V7, V9, V10), hence, the protection works did not affect the radiation situation in the near-portal areas;
2. Tunnels where maximal values of β-flux density decreased whereas the values of average contamination densities changed insignificantly – within the measurement errors of the corresponding quantity (G5, V8, GV1). It is the result of decontamination measures before works. Insignificant variations in the average density show that maximal values of β-flux density registered during preliminary inspection were detected only in small local spots, which did not make any considerable contribution to the average density;
3. Tunnels where maximal values of β-flux density decreased whereas the values of average contamination densities changed insignificantly (G6, V6), which may be a result of contamination by beta-radiating radionuclides during protection works. Insignificant variations in the average density are caused by insignificant increase in the maximal values of β-flux density registered during the final in-

spection as well as local contamination, which did not make any considerable contribution to the average density.

As a result of the analysis the following conclusions were made:

1. V9 – the protection works did not affect the radiation situation on the territory of the tunnel.
2. G5, G7, V8, V10, GV1 – decontamination carried out on the near-portal areas before works improved the radiation situation.
3. G6, V6 – contamination of the area caused by protection works is local with insignificant increase in radiation parameters.

6.2. Variations in the radionuclide contamination of the surface soil layer

After final inspection of the near-portal tunnel areas, variations in the radioecological situation in the studied areas were evaluated. Maximal values of soil contamination with artificial radionuclides registered in the preliminary and final inspections are presented in the histogram (Figure 45).

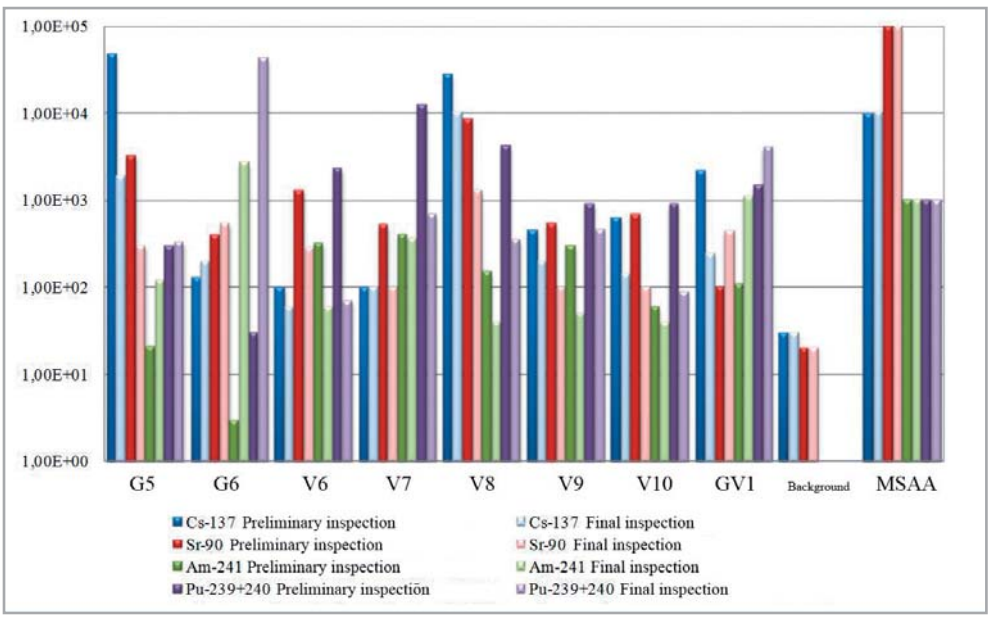


Figure 45. A comparison of maximal values of radionuclide specific activities registered in the preliminary and final inspections of the near-portal tunnel areas, Bq/kg

In all the tunnels with vertical additional protection, maximal values of specific activities of artificial radionuclides decreased, as before conservation works in order to reduce radiation influence on the personnel, the territory was decontaminated with removal of local contaminations, and after conservation works the contaminated ground extracted during drilling was removed from the area.

In the tunnels with horizontal additional protection, an increase in local maximal activities of transuranium radionuclides ^{241}Am and $^{239+240}$ was registered, which indicates carrying-out of contamination from the tunnel cavities. Significant increase in activities was observed in the local area of tunnel G6, where the final inspection registered the maximal specific activity of ^{241}Am equal to $2.7 \cdot 10^3$ Bq/kg; as the ratio of $^{239+240}$Pu to ^{241}Am in the tunnel was 1:16, the maximal specific activity of $^{239+240}$Pu could be as high as $4.3 \cdot 10^4$ Bq/kg.

Increase in maximal values of ^{90}Sr specific activity was only observed in two tunnels (G6 – by a factor of 1.4, GV1 – by a factor of 4.5), an increase in ^{137}Cs activity was only observed on the near-portal area of tunnel G6 with a 1.5 increase in activity during preliminary examination.

As a whole, in order to analyze variations in the radiation situation in the near-portal areas, one can compare the average values of concentrations of artificial radionuclides in soil. The average values of specific activities of all studied radionuclides in all near-portal areas calculated taking into account all sampling points in the area are presented in Table 3.

A comparative analysis of variations in the average specific activity of radionuclides in soil showed improvement in the radiation situation and considerable decrease in average specific activities of artificial radionuclides in tunnels with vertical additional protection. In most cases specific activities of radionuclides decreased after measures on reduction of radiation hazard on radioactively-contaminated spots. In tunnels with horizontal and combined additional protection an increase in average values indicates on areal redistribution of contaminated soil on the near-portal areas of tunnels.

As a whole, variations in maximal and average values of specific activities of artificial radionuclides on the inspected near-portal tunnel areas before and after conservation works enabled us to subdivide tunnels by the character of variations in the radiation situation:

1. Tunnels where maximal and average values of specific activities of artificial radionuclides in soil decreased, which is indicative of improvement in the near-portal radiation situation due to measures on reduction of radiation hazard on radioactively-contaminated spots (V6-V9);
2. Tunnels where only concentration of transuranium radionuclides ^{241}Am and/or $^{239+240}$Pu in soil increased, which was caused by redistribution of contaminated soil over the territory as a result of conservation works (G5< V10, GV1);
3. The tunnel where the concentration of radionuclides ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu increased, which was the result of redistribution of radionuclides during works on additional protection (G6).

Table 3.

A summary table of radiation parameters on the territory of near-portal areas of the tunnels of the Degelen mountain massif by the results of 2009-2010 preliminary and final inspection

Parameter		G5	G6	V6	V7	V8	V9	V10	GV1
Maximal EDR value, μSv/h	Preliminary inspection	0.86±0.17	1.02±0.20	0.30±0.06	0.63±0.13	0.98±0.20	0.23±0.05	0.63±0.13	0.41±0.08
	Final inspection	0.33±0.07	1.02±0.20	0.78±0.16	0.37±0.07	0.65±0.07	0.20±0.04	0.32±0.06	0.41±0.08
Average contamination density by EDR measurements, μSv/h	Preliminary inspection	0.32±0.10	0.33±0.10	0.22±0.07	0.29±0.09	0.25±0.08	0.22±0.07	0.24±0.07	0.31±0.09
	Final inspection	0.20±0.06	0.28±0.08	0.23±0.07	0.20±0.06	0.20±0.06	0.16±0.05	0.23±0.07	0.29±0.09
Maximal value of beta-flux density, part/(min·cm^2)	Preliminary inspection	220±44	18±4	10±3	10±2	52±10	10±2	16±3	20±4
	Final inspection	12±2	35±7	24±5	10±2	31±6	10±2	18±4	10±2
Average contamination density by measurements of the beta-flux density, part/(min·cm^2)	Preliminary inspection	11±3	10±3	10±3	10±3	12±4	10±3	11±3	11±3
	Final inspection	12±4	12±4	10±3	10±3	12±4	10±3	11±3	10±3
Maximal value of alpha-flux density, part/(min·cm^2)	Preliminary inspection	<1	<1	<1	<1	<1	<1	<1	<1
	Final inspection	<1	<1	<1	<1	<1	<1	<1	<0.2
Maximal value of volumetric activity in air during preliminary inspection, Bq/m^3	^{137}Cs	$<5.6\cdot10^{-4}$	$<8.5\cdot10^{-4}$	$<2.8\cdot10^{-4}$	$<5.6\cdot10^{-4}$	$<4.4\cdot10^{-4}$	$<7.0\cdot10^{-4}$	$<1.0\cdot10^{-3}$	$<1.0\cdot10^{-3}$
	^{241}Am	$<2.5\cdot10^{-4}$	$<2.5\cdot10^{-4}$	$<3.5\cdot10^{-5}$	$<2.5\cdot10^{-4}$	$<2.5\cdot10^{-4}$	$<2.0\cdot10^{-4}$	$<2.5\cdot10^{-4}$	$<6.0\cdot10^{-4}$

Parameter			G5	G6	V6	V7	V8	V9	V10	GV1
Maximal value of specific activity, Bq/kg	**^{137}Cs**	Preliminary inspection	$4.9 \cdot 10^{4} \pm 1.0 \cdot 10^{4}$	$1.3 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$2.8 \cdot 10^{4} \pm 0.6 \cdot 10^{4}$	$4.5 \cdot 10^{2} \pm 0.9 \cdot 10^{2}$	$6.4 \cdot 10^{2} \pm 1.2 \cdot 10^{2}$	$2.2 \cdot 10^{3} \pm 0.4 \cdot 10^{3}$
		Final inspection	$1.9 \cdot 10^{3} \pm 0.4 \cdot 10^{3}$	$2.0 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$6.0 \cdot 10^{1} \pm 1.2 \cdot 10^{1}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.0 \cdot 10^{4} \pm 0.2 \cdot 10^{4}$	$2.0 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$1.4 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$2.4 \cdot 10^{2} \pm 0.5 \cdot 10^{2}$
	^{90}Sr	Preliminary inspection	$3.2 \cdot 10^{3} \pm 0.6 \cdot 10^{3}$	$4.0 \cdot 10^{2} \pm 0.8 \cdot 10^{2}$	$1.3 \cdot 10^{3} \pm 0.2 \cdot 10^{3}$	$5.2 \cdot 10^{2} \pm 1.0 \cdot 10^{2}$	$8.7 \cdot 10^{3} \pm 1.6 \cdot 10^{3}$	$5.4 \cdot 10^{2} \pm 1.0 \cdot 10^{2}$	$7.0 \cdot 10^{2} \pm 1.4 \cdot 10^{2}$	$<1.0 \cdot 10^{2}$
		Final inspection	$3.0 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$5.4 \cdot 10^{2} \pm 1.0 \cdot 10^{2}$	$2.9 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.3 \cdot 10^{3} \pm 0.2 \cdot 10^{3}$	$<1.0 \cdot 10^{2}$	$<1.0 \cdot 10^{2}$	$4.5 \cdot 10^{2} \pm 0.9 \cdot 10^{2}$
	^{241}Am	Preliminary inspection	$2.1 \cdot 10^{1} \pm 0.4 \cdot 10^{1}$	$3.0 \cdot 10^{0} \pm 0.6 \cdot 10^{0}$	$3.2 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$4.1 \cdot 10^{2} \pm 0.8 \cdot 10^{2}$	$1.5 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$3.0 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$6.0 \cdot 10^{1} \pm 1.2 \cdot 10^{1}$	$1.1 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$
		Final inspection	$1.2 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$2.7 \cdot 10^{3} \pm 0.5 \cdot 10^{3}$	$6.0 \cdot 10^{1} \pm 1.2 \cdot 10^{1}$	$3.6 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$4.0 \cdot 10^{1} \pm 0.8 \cdot 10^{1}$	$5.0 \cdot 10^{1} \pm 1.0 \cdot 10^{1}$	$4.0 \cdot 10^{1} \pm 0.8 \cdot 10^{1}$	$1.1 \cdot 10^{3} \pm 0.2 \cdot 10^{3}$
	$^{239+240}$Pu	Preliminary inspection	$3.0 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$3.0 \cdot 10^{1} \pm 0.6 \cdot 10^{1}$	$2.3 \cdot 10^{3} \pm 0.4 \cdot 10^{3}$	$1.2 \cdot 10^{4} \pm 0.2 \cdot 10^{4}$	$4.2 \cdot 10^{3} \pm 0.8 \cdot 10^{3}$	$9.0 \cdot 10^{2} \pm 1.8 \cdot 10^{2}$	$9.0 \cdot 10^{2} \pm 1.8 \cdot 10^{2}$	$1.5 \cdot 10^{3} \pm 0.3 \cdot 10^{3}$
		Final inspection	$3.3 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$4.3 \cdot 10^{4} \pm 0.9 \cdot 10^{4}$	$7.0 \cdot 10^{1} \pm 1.4 \cdot 10^{1}$	$7.0 \cdot 10^{2} \pm 1.4 \cdot 10^{2}$	$3.5 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$4.6 \cdot 10^{2} \pm 0.9 \cdot 10^{2}$	$9.0 \cdot 10^{1} \pm 1.8 \cdot 10^{1}$	$4.1 \cdot 10^{3} \pm 0.8 \cdot 10^{3}$
Average value of specific activity, Bq/kg	^{137}Cs	Preliminary inspection	$2.8 \cdot 10^{3} \pm 0.5 \cdot 10^{3}$	$3.2 \cdot 10^{1} \pm 0.6 \cdot 10^{1}$	$3.1 \cdot 10^{1} \pm 0.6 \cdot 10^{1}$	$2.9 \cdot 10^{1} \pm 0.6 \cdot 10^{1}$	$2.5 \cdot 10^{3} \pm 0.5 \cdot 10^{3}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.1 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.6 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$
		Final inspection	$3.1 \cdot 10^{2} \pm 0.6 \cdot 10^{2}$	$3.4 \cdot 10^{1} \pm 0.6 \cdot 10^{1}$	$1.7 \cdot 10^{1} \pm 0.3 \cdot 10^{1}$	$2.0 \cdot 10^{1} \pm 0.4 \cdot 10^{1}$	$8.5 \cdot 10^{2} \pm 1.6 \cdot 10^{2}$	$4.0 \cdot 10^{1} \pm 0.8 \cdot 10^{1}$	$3.9 \cdot 10^{1} \pm 0.8 \cdot 10^{1}$	$6.7 \cdot 10^{1} \pm 1.2 \cdot 10^{1}$
	^{90}Sr	Preliminary inspection	$2.6 \cdot 10^{2} \pm 0.5 \cdot 10^{2}$	$2.1 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$1.7 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$1.2 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$8.5 \cdot 10^{2} \pm 1.6 \cdot 10^{2}$	$1.5 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$1.3 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$
		Final inspection	$1.8 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$1.6 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$1.1 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.9 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.0 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.3 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$
	^{241}Am	Preliminary inspection	$4.0 \cdot 10^{0} \pm 0.8 \cdot 10^{0}$	$1.0 \cdot 10^{0} \pm 0.2 \cdot 10^{0}$	$1.7 \cdot 10^{1} \pm 0.3 \cdot 10^{1}$	$5.5 \cdot 10^{1} \pm 1.0 \cdot 10^{1}$	$9.0 \cdot 10^{0} \pm 1.8 \cdot 10^{0}$	$7.2 \cdot 10^{1} \pm 1.4 \cdot 10^{1}$	$6.0 \cdot 10^{0} \pm 1.2 \cdot 10^{0}$	$1.1 \cdot 10^{1} \pm 0.2 \cdot 10^{1}$
		Final inspection	$1.3 \cdot 10^{1} \pm 0.3 \cdot 10^{1}$	$1.6 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$1.1 \cdot 10^{1} \pm 0.2 \cdot 10^{1}$	$6.2 \cdot 10^{1} \pm 1.2 \cdot 10^{1}$	$9.0 \cdot 10^{0} \pm 1.8 \cdot 10^{0}$	$1.6 \cdot 10^{1} \pm 0.3 \cdot 10^{1}$	$9.0 \cdot 10^{0} \pm 1.8 \cdot 10^{0}$	$7.7 \cdot 10^{1} \pm 1.4 \cdot 10^{1}$
	$^{239+240}$Pu	Preliminary inspection	$9.5 \cdot 10^{1} \pm 1.8 \cdot 10^{1}$	$9.0 \cdot 10^{0} \pm 1.8 \cdot 10^{0}$	$1.2 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$1.7 \cdot 10^{3} \pm 0.3 \cdot 10^{3}$	$2.6 \cdot 10^{2} \pm 0.5 \cdot 10^{2}$	$2.1 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$9.3 \cdot 10^{1} \pm 1.8 \cdot 10^{1}$	$1.3 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$
		Final inspection	$1.5 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$2.7 \cdot 10^{3} \pm 0.5 \cdot 10^{3}$	$2.6 \cdot 10^{1} \pm 0.5 \cdot 10^{1}$	$2.3 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$7.5 \cdot 10^{1} \pm 1.4 \cdot 10^{1}$	$1.2 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$2.6 \cdot 10^{1} \pm 0.5 \cdot 10^{1}$	$6.3 \cdot 10^{2} \pm 1.2 \cdot 10^{2}$
Average areal contamination, Bq/m^2	**^{137}Cs**	Preliminary inspection	$3.9 \cdot 10^{4}$	$3.9 \cdot 10^{3}$	$3.2 \cdot 10^{3}$	$3.0 \cdot 10^{3}$	$1.4 \cdot 10^{4}$	$9.0 \cdot 10^{3}$	$8.4 \cdot 10^{3}$	$7.3 \cdot 10^{3}$
		Final inspection	$2.2 \cdot 10^{4}$	$4.5 \cdot 10^{3}$	$2.2 \cdot 10^{3}$	$3.3 \cdot 10^{3}$	$1.1 \cdot 10^{4}$	$2.6 \cdot 10^{3}$	$4.6 \cdot 10^{3}$	$6.9 \cdot 10^{3}$
	^{241}Am	Preliminary inspection	$5.0 \cdot 10^{2}$	$1.1 \cdot 10^{2}$	$2.2 \cdot 10^{2}$	$2.9 \cdot 10^{3}$	$3.5 \cdot 10^{2}$	$4.9 \cdot 10^{3}$	$2.9 \cdot 10^{2}$	$6.8 \cdot 10^{2}$
		Final inspection	$2.1 \cdot 10^{3}$	$2.1 \cdot 10^{3}$	$1.7 \cdot 10^{3}$	$7.3 \cdot 10^{3}$	$1.4 \cdot 10^{3}$	$1.4 \cdot 10^{3}$	$6.8 \cdot 10^{2}$	$3.6 \cdot 10^{3}$

CONCLUSION

In 2009 –2010 in the framework of the project on liquidation of the nuclear tests infrastructure, 8 tunnels of the Degelen mountain massif at the Semipalatinsk test site were re-conserved. Radioecological survey of the near-portal areas before and after the works on construction of additional protection enabled us to evaluate the impact of the conservation works on the environment.

It is possible to make a conclusion that as a result of the conservation works using vertical method of additional protection, the radiation situation was improved due to decontamination measures. Usage of horizontal or combined methods of additional protection might have caused local contamination of near-portal areas and in some cases it really happened. In such a situation it is necessary to organize temporary storage facilities for working instruments and appliances as well as temporary disposal facilities for storage of ground removed from the tunnels.

As a whole, the system controlling the radiological situation with preliminary and final inspections in each controlled area makes it possible to improve the radioecological situation, which is an important factor in assuring safety of personnel and population.

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ФИЗИКАЛЫҚ ТОСҚАУЫЛДАРДЫ КҮШЕЙТУ БОЙЫНША ЖҰМЫСТАР ӨТКІЗІЛГЕНГЕ ДЕЙІН ЖӘНЕ КЕЙІН ДЕГЕЛЕҢ ТАУЛЫ МАССИВІНДЕГІ ШТОЛЬНЯЛАРДЫҢ ПОРТАЛАЛДЫ ТЕЛІМДЕРІНІҢ РАДИАЦИЯЛЫҚ ХАЛ-АХУАЛЫ

Коровикова Т.В., Мустафина Е.В., Осинцев А.Ю., Дмитропавленко В.Н., Яковенко Ю.Ю.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Ядролық қарудың таратылу қатерін төмендету мақсатында ядролық сынақтардың инфрақұрылымын жою бойынша жұмыстардың шеңберінде (2009-2010 жж.) Семей сынақ полигонындағы Дегелең таулы массивінің 8 штольнясын қайта жабу жұмысы өткізілді. Аталған радиоэкологиялық зерттеулердің мақсаты қоршаған орта нысандарының хал-ахуалын, сонымен қатар аталған штольнялардың порталалды телімдерінде өткізілген жұмыстардың теріс әсер ету мүмкіндігін бағалау. Бақылаудағы әрбір штольняның порталалды теліміндегі радиоэкологиялық жағдайдың өзгерісінің нәтижелері келтірілді.

Түйін сөздер: Семей сынақ полигоны, Дегелең таулы массиві, штольнялар, инженерлік құрылғыларды қосымша қорғау, радиоэкологиялық зерттеу, радиациялық хал-ахуал, эквивалентті доза қуаты, α-, β-бөлшек ағымының тығыздығы, радионуклид, тиесілі белсенділік, штольнялар.

РАДИАЦИОННАЯ ОБСТАНОВКА НА ПРИПОРТАЛЬНЫХ УЧАСТКАХ ШТОЛЕН ГОРНОГО МАССИВА ДЕГЕЛЕН ДО И ПОСЛЕ ПРОВЕДЕНИЯ РАБОТ ПО УСИЛЕНИЮ ФИЗИЧЕСКИХ БАРЬЕРОВ

Коровикова Т.В., Мустафина Е.В., Осинцев А.Ю., Дмитропавленко В.Н., Яковенко Ю.Ю.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В рамках работ (2009–2010 гг.) по ликвидации инфраструктуры ядерных испытаний в целях уменьшения угрозы распространения ядерного оружия было проведено повторное консервирование 8 штолен горного массива Дегелен Семипалатинского испытательного полигона. Целью данных радиоэкологических исследований являлась оценка состояния объектов окружающей среды, а также возможного негативного влияния проведенных работ на припортальных участках данных штолен. Представлены результаты изменения радиоэкологической обстановки на припортальных участках каждой контролируемой штольни.

Ключевые слова: Семипалатинский испытательный полигон, горный массив Дегелен, штольни, дополнительная защита инженерных сооружений, радиоэкологическое обследование, радиационная обстановка, мощность эквивалентной дозы, плотность потока α-, β-частиц, радионуклид, удельная активность.

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FEATURES OF RADIOACTIVE CONTAMINATION OF THE ZHAKSYTUZ SALT DEPOSIT AREA

Aidarkhanov A.O., Lukashenko S.N., Lyakhova O.N.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

The paper presents the results of radioecological investigations in "Zhaksytuz" salt deposit area located at the border of the "Experimental field" of the former Semipalatinsk Test Site (STS). A distinctive feature of the deposit is the mechanism of continuous formation of the productive salt bed. Thus, the surface of the lake, contaminated by the fallout from nuclear testing about 50 years ago, is now deep in the newly formed salt beds. It has been established that the major surface contamination with artificial radionuclides is concentrated in soils and subsoils of the deposit's shoreline. In the deposit's productive strata no significant concentrations of artificial radionuclides have been found.

Keywords: "Zhaksytuz" salt deposit, Semipalatinsk Test Site, radioactive contamination, radionuclides, areal contamination.

INTRODUCTION

"Zhaksytuz" salt deposit is located at a distance of 60 km to the southwest from Kurchatov-city, in Maisky rayon of Pavlodar oblast.

Zhaksytuz is a closed lake without constant water inflows, the lake has an isometric-oval shape slightly elongated in the meridian direction. The area of the lake is 2.3x3 km. The shores, 2-3 m high, are flat turning into 40-50 m-wide solonchak plain. Formation of the salt stratum depends on the presence of surface saturated salt solution (brine) and its evaporation.

Lithologic section of the lake:

- 0.00-0.05 m – novosadka sediments (unsteady);
- 0.00-0.50 m – starosadka stratum;
- 0.50-10.50 m – karatuz with silt gradually passing into silt and further into clayish sediments [1, 2].

A specific feature of the deposit is its location. It is located on the territory of the former STS close to the border of the test ground "Experimental field" (Figure 1).

Previous investigations showed that nuclear weapons tests on the "Experimental field" caused radioactive contamination of the area located beyond the test ground. This fact enabled scientists to make an assumption that the territory of the deposit is contaminated by artificial radionuclides.

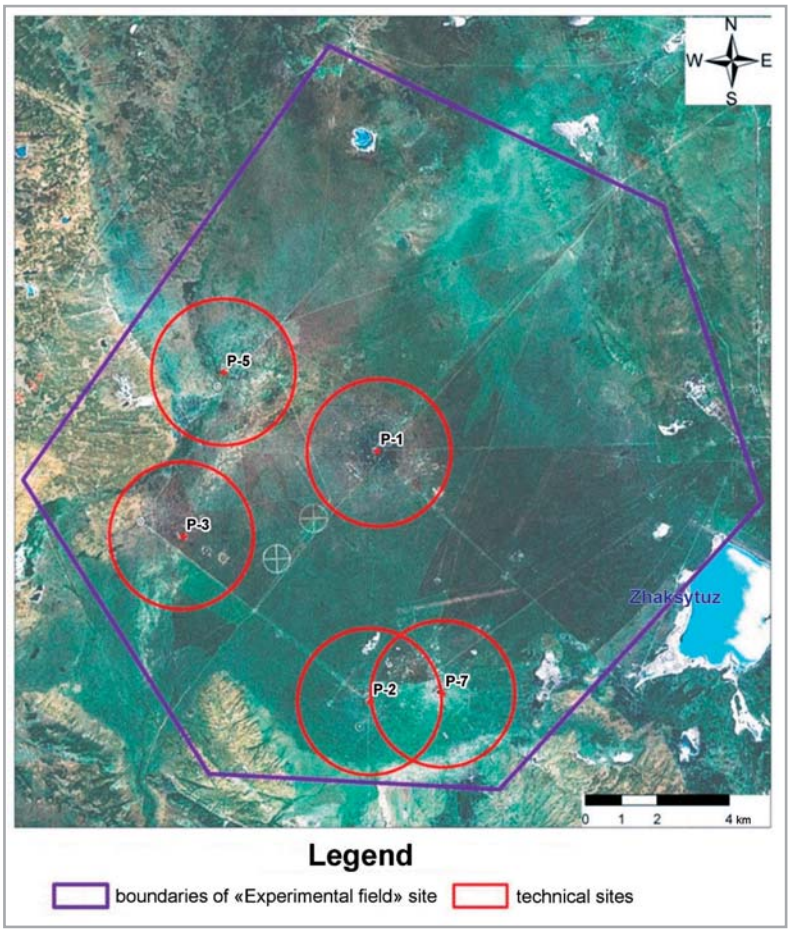


Figure 1. Spatial location of Zhaksytuz lake

The aim of the present research is to study the present-day radiation situation in the deposit area and to reveal factors forming the type of radionuclide contamination of the area.

In order to solve the problem it was necessary to do the following works:

1. To study the levels of contamination of soils and subsoils of the deposit's shoreline by artificial radionuclides.
2. To study the character of vertical and horizontal distribution of radionuclides in the salt strata.
3. To study the forms of radionuclides in the salt strata.

1. EXPERIMENTAL PART

1.1. Field works

In the shoreline of the lake surface soil samples were taken. The samples were collected at equal distances along the perimeter of the lake at a distance of 100 m from the shoreline. Such a distance was taken in order to exclude sampling in the solonchak area subjected to underflooding during floods. The sampling scheme is shown in Figure 2. The samples were taken at a depth of 0-5 cm from the area of 100 cm^2. The samples were packed in the polyethylene bag containing their passport with the following data: date of sampling, place of sampling, geographical coordinates, radiation parameters in the place of sampling, etc. The samples were taken and packed according to the requirements to soil sampling in areas with global and local contaminations [3]. During sampling EDR at a height of 0.03 m and 1m above the soil level and β-flux density were measured.

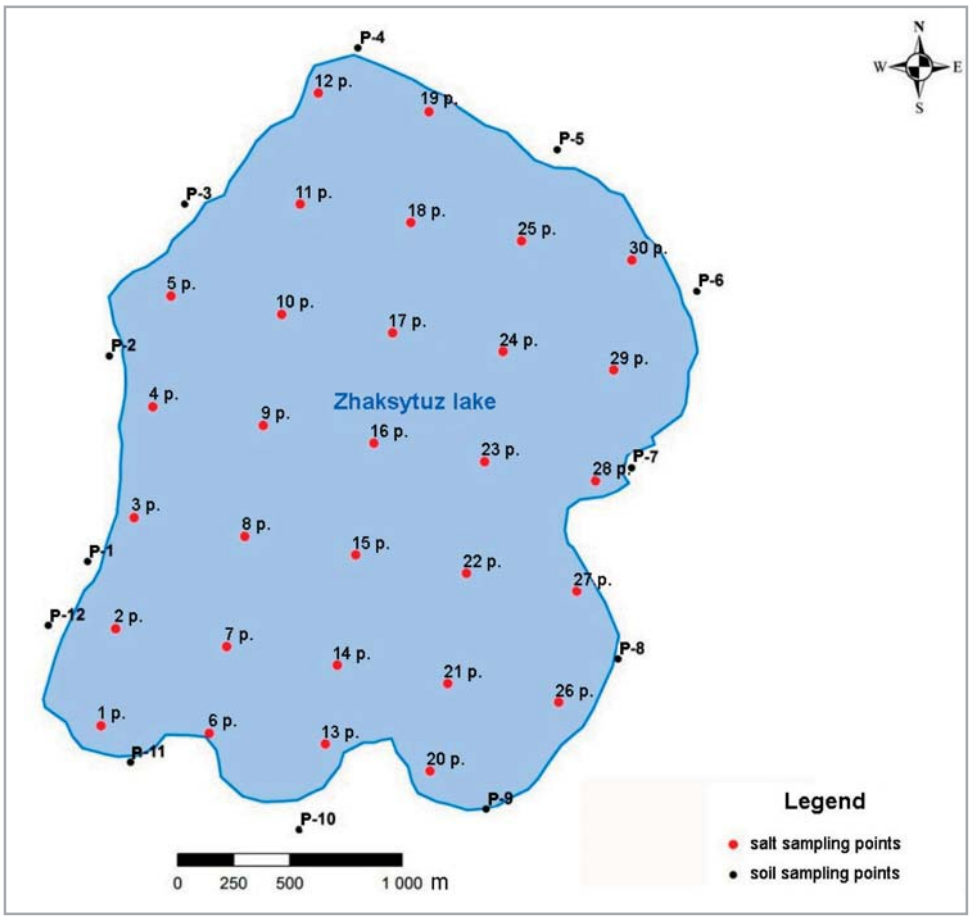


Figure 2. A sampling scheme

Samples of the salt stratum were taken over the whole area using a grid with a step of 500×500 m. In each point the samples were taken layer-by-layer at different depths (Figure 2). The samples were taken with special instruments designed to take samples layer-by-layer from a given depth. As different types of salt sediments are distributed non-uniformly, the boundaries of different layers were determined visually directly at the moment of sampling. The thickness of the "novosadka" layer was up to 10 cm, the "starosadka" layer was not thicker than 40 cm, the thickness of the "karatuz" was 90 cm and that of the "bottom sediments" was 130 cm.

The samples were sent to the laboratory in order to determine specific activity of artificial radionuclides.

1.2. Laboratory analysis

Preparation of soil and salt samples

To prepare the samples for laboratory γ-spectrometric analysis according to GOST 17.4.4.02-84 [4] the following operations were made:

1. Extraction of impurities (vegetation and stones) from the main volume of the sample;
2. Drying up to a constant weight;
3. Sieving of samples through a 2 mm sieve;
4. Grinding of fractions less than 2 mm on the mill to a size of 200 mesh (≤0.074 mm);
5. Quartering;
6. Placement of a specimen of a volume of ≈500 g in the calibration vessel (Petri dish) for γ-spectrometric measurements.

Samples for radiochemical analysis for $^{239+240}$Pu and ^{90}Sr were prepared according to the scheme:

1. Choice of a specimen (not less than 50 g) from the sample which passed γ-spectrometric analysis;
2. Ashing of the specimen in the muffle furnace for 8 hours at 600º C with periodic stirring.

Analysis of samples by γ-spectrometry

In order to determine concentration of γ-radiating radionuclides we used γ-spectrometers produced by Canberra and Ortec.

For energy calibration of spectrometers a set of standard γ-sources (OSGI) was used, for geometry calibration special-purpose volumetric activity standards (OMASN) containing radionuclides ^{137}Cs, ^{152}Eu and ^{241}Am were used. A sample of a mass ≈500 g obtained during sample preparation was placed on the detector window for measurements. The measurements were made according to the certified methodology [5].

Determination of $^{239+240}$Pu concentration in the environmental objects

Radiochemical analysis of concentration of plutonium isotopes in the environment samples was made using radiochemical technique [6]. α-spectrometric measurements were made on Canberra α-spectrometers. The obtained results were processed using Genie-2000 software developed by Canberra for α-spectrometer.

Determination of ^{90}Sr concentration in the environmental objects

^{90}Sr concentration in the environmental samples (soil, water, air aerosols and vegetation) was determined according to the certified methodological instructions and methods [7, 8] using β-spectrometer TRI-CARB 2900TR and a software package QuantaSmart.

Relative registration efficiency used for analysis of spectrometers was not lower than 20 %. The time of measurement of each sample was not less than 2 hours.

Determination of radionuclide forms in the deposit

To determine the forms of radionuclides we chose samples with the highest specific activity of artificial radionuclides. Preference was given to the samples taken in different points of the salt strata at different depths. The whole volume of the sample of the volume 1-1.5 kg was dissolved in the distilled water during heating. The obtained solutions were filtered through the double layer of filter paper. The filtrate was a transparent colorless liquid. The dry residue in the filter was a grayish mixture in the form of silt. The filtrate and the dry residue on the filter were subjected to the γ-spectrometric and radiochemical analyses.

As a result of analytical investigations the following values of minimally detected specific activities were obtained (Table 1). The values depended on the mass of the sample provided for research and time of measurement.

Table 1.

Values of minimally detected specific activities (MDSA)

Bq/kg						
^{137}Cs	^{241}Am	^{152}Eu	^{154}Eu	^{60}Co	$^{239+240}Pu$	^{90}Sr
3	3	2	2	2	1-3	1

2. RESULTS OF INVESTIGATIONS

The radiometric measurements showed that the values of radiation parameters on the territory of the lake and in the shoreline ranged in the following intervals: MED – 0.10-0.14 μSv/h, the beta-particles density was <10 part./(min*cm^2). No radioactively contaminated spots have been revealed.

2.1. Investigation of radionuclide composition of soils and subsoils

The results of laboratory gamma-spectrometric measurements are presented in the Table 2. For radiochemical investigations of $^{239+240}Pu$ and ^{90}Sr concentrations 3 samples, in which maximal concentration of ^{241}Am was registered, were chosen.

Table 2.

Content of artificial radionuclides in soil

Sampling point	Concentration of gamma-radiating radionuclides, Bq/kg						
	^{241}Am	^{137}Cs	^{152}Eu	^{154}Eu	^{60}Co	$^{239+240}Pu$	^{90}Sr
P-1	<3	7 ± 1	< 2	<3	<3	-	-
P-2	7 ± 1	7 ± 1	< 2	< 2	<3	-	-
P-3	<4	7 ± 1	< 2	< 2	< 2	-	-

Sampling point	Concentration of gamma-radiating radionuclides, Bq/kg						
	^{241}Am	^{137}Cs	^{152}Eu	^{154}Eu	^{60}Co	$^{239+240}$Pu	^{90}Sr
P-4	100 ± 10	40 ± 4	< 2	<3	< 2	-	17 ± 1
P-5	90 ± 9	35 ± 3	< 2	< 2	<3	-	-
P-6	15 ± 1	25 ± 2	<3	<2	<3	-	-
P-7	200 ± 20	45 ± 4	<5	< 2	<3	320 ± 40	37 ± 1
P-8	55 ± 5	60 ± 6	< 2	< 2	< 2	-	-
P-9	250 ± 20	150 ± 10	<6	< 2	<3	830 ± 60	23 ± 1
P-10	70 ± 7	35 ± 3	<3	< 2	<3	-	-
P-11	60 ± 6	10 ± 1	< 2	< 2	< 2	-	-
P-12	<3	10 ± 1	< 2	< 2	< 3	-	-

The data presented in the table show that soils and subsoils were almost everywhere contaminated with artificial radionuclides ^{241}Am and ^{137}Cs. No products of ^{152}Eu, ^{154}Eu and ^{60}Co fission and activation were detected. The presence of $^{239+240}$Pu and ^{90}Sr was detected in all sampling points.

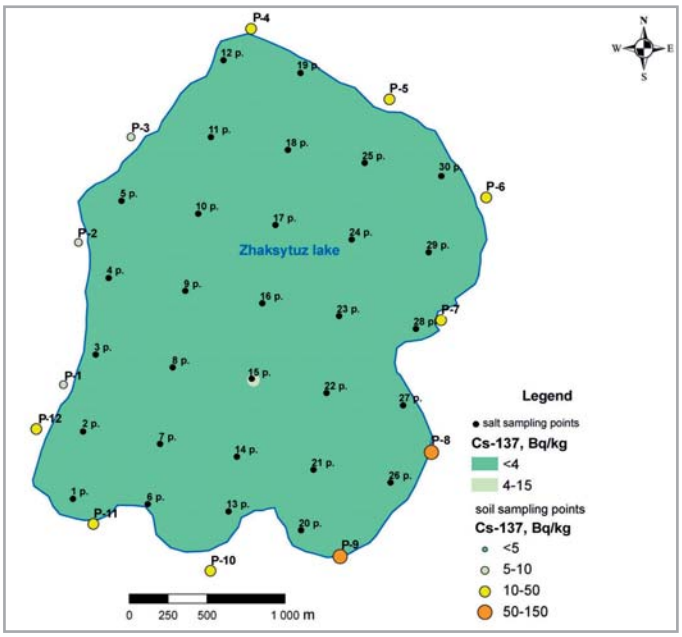
Qualitative data on the contents of radionuclides in the upper layer of the salt strata were obtained in the three sampling points only; in the other points specific activity was below minimally detected values. In the graphic form the results of determination of artificial radionuclides in the shoreline soils and in the surface salt layer are presented in Figure 3.

It is seen from the figure that no significant concentrations of ^{137}Cs and ^{241}Am are registered in the surface layer of the deposit, and their specific activity on the most part of the studied area is less than 4 Bq/kg.

Quantitative values of specific activity of artificial radionuclides were determined in soils and subsoils and were concentrated along the shoreline of the lake.

2.2. Investigation of the character of distribution of artificial radionuclides in the productive strata

In the samples collected along the lithologic section (in depth) only radionuclides ^{241}Am and ^{7}Cs were detected. The results of laboratory gamma-spectrometric measurements are presented in Table 3.



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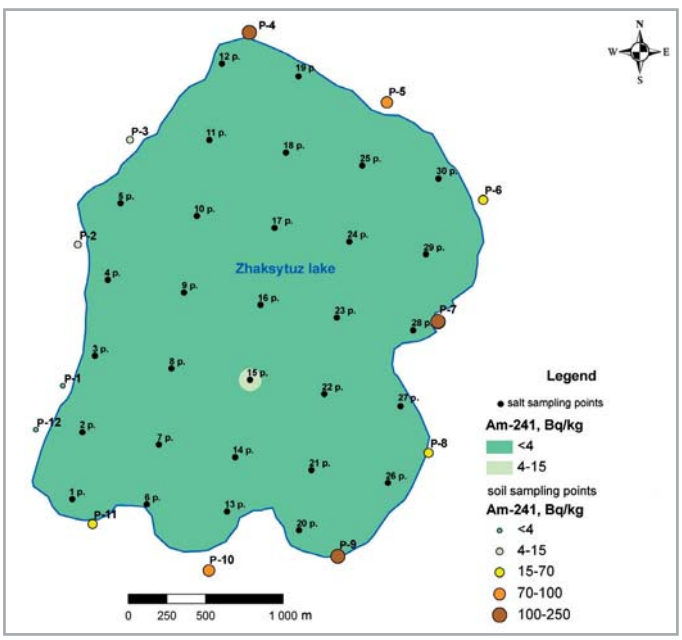


b)

Figure 3. A schematic map of the areal distribution a) ^{137}Cs and b) ^{241}Am

Table 3.

Results of laboratory gamma-spectrometric measurements

Sampling point	Sampling depth, cm	Stratum type	^{241}Am	^{137}Cs	Sampling point	Sampling depth, cm	Stratum type	^{241}Am	^{137}Cs
			Bq/kg					Bq/kg	
p-1/1	0-5	novosadka	<3	<3	p-16/2	3-10	novosadka	<3	<3
p-1/2	5-15	bottom	10±1	30±3	p-16/3	10-20	starosadka	9±1	4±1
p-2/1	0-10	novosadka	<3	<3	p-16/4	20-30	bottom	<3	4±1
p-2/2	10-20	starosadka	7±1	<3	p-16/5	60-70	bottom	<3	3±1
p-2/3	20-30	bottom	20±2	<3	p-17/1	0-10	novosadka	<3	<3
p-2/4	90-100	bottom	<3	<3	p-17/2	10-20	starosadka	5±1	<3
p-3/1	0-10	novosadka	<3	<3	p-17/3	20-30	bottom	3±1	<3
p-3/2	10-20	starosadka	<3	<3	p-17/4	40-50	bottom	<3	3±1
p-3/3	40-50	bottom	<3	<3	p-18/1	0-10	novosadka	<3	<3
p-3/4	90-100	bottom	<3	3±1	p-18/2	10-20	starosadka	15±1	<3
p-4/1	0-10	novosadka	<3	<3	p-18/3	20-30	bottom	3±1	3±1
p-4/2	10-20	starosadka	<3	<3	p-18/4	100-120	bottom	<3	<3
p-4/3	20-30	bottom	3±1	3±1	p-19/1	0-10	novosadka	<3	<3
p-4/4	80-90	bottom	<3	<3	p-19/2	10-20	starosadka	<3	<3
p-5/1	0-10	novosadka	<3	<3	p-19/3	20-30	bottom	<3	<3
p-5/2	10-20	starosadka	<3	<3	p-19/4	120-130	bottom	<3	<3
p-5/3	20-30	bottom	<3	<3	p-20/1	0-5	novosadka	<3	<3
p-5/4	40-50	bottom	7±1	3±1	p-20/2	5-15	bottom	20±2	25±2
p-6/1	0-5	novosadka	<3	<3	p-20/3	60-70	bottom	7±1	10±1
p-6/2	5-15	bottom	9±1	50±5	p-21/1	0-10	novosadka	<3	3±1
p-7/1	0-3	novosadka	<3	<3	p-21/2	10-20	starosadka	4±1	<3
p-7/2	3-10	novosadka	4±1	4±1	p-21/3	20-30	bottom	<3	3±1
p-7/3	10-20	starosadka	15±1	10±1	p-21/4	50-60	bottom	<3	3±1
p-7/4	20-30	bottom	3±1	4±1	p-22/1	0-10	starosadka	<3	<3
p-7/5	60-70	bottom	<3	<3	p-22/2	10-15	starosadka	3±1	5±1
p-8/1	0-10	novosadka	<3	<3	p-22/3	15-25	bottom	5±1	9±1
p-8/2	10-20	starosadka	<3	3±1	p-22/4	40-50	bottom	<3	<3
p-8/3	20-30	bottom	<3	6	p-23/1	0-10	novosadka	<3	<3
p-8/4	60-70	bottom	<3	<3	p-23/2	10-20	starosadka	3±1	3±1
p-9/1	0-10	novosadka	<3	<3	p-23/3	20-30	bottom	<3	3±1
p-9/2	10-20	starosadka	4±1	3±1	p-23/4	50-60	bottom	<3	<3
p-9/3	20-30	karatuz	<3	3±1	p-24/1	0-10	novosadka	<3	<3
p-9/4	40-50	bottom	3±1	6±1	p-24/2	10-20	starosadka	6±1	4±1
p-10/1	0-10	novosadka	<3	<3	p-24/3	20-30	bottom	<3	5±1
p-10/2	10-20	starosadka	8±1	5±1	p-25/1	0-3	novosadka	<3	<3
p-10/3	20-30	karatuz	3±1	4±1	p-25/2	3-10	novosadka	<3	<3
p-10/4	70-80	bottom	<3	<3	p-25/3	10-20	starosadka	3±1	<3

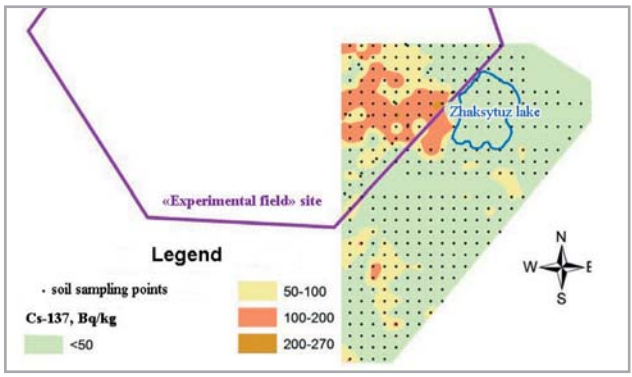
Sampling point	Sampling depth, cm	Stratum type	^{241}Am	^{137}Cs	Sampling point	Sampling depth, cm	Stratum type	^{241}Am	^{137}Cs
			Bq/kg					Bq/kg	
p-11/1	0-3	novosadka	<3	<3	p-25/4	20-30	karatuz	<3	<3
p-11/2	3-10	novosadka	<3	<3	p-25/5	70-80	bottom	<3	<3
p-11/3	10-20	starosadka	<3	3±1	p-26/1	0-3	novosadka	3±1	<3
p-11/4	30-50	karatuz	7±1	4±1	p-26/2	3-10	starosadka	3±1	4±1
p-11/5	70-80	bottom	<3	<3	p-26/3	20-30	karatuz	<3	7±1
p-12/1	0-10	novosadka	<3	<3	p-26/4	40-50	bottom	<3	3±1
p-12/2	10-20	starosadka	<3	<3	p-27/1	0-3	novosadka	<3	<3
p-12/3	40-50	karatuz	5±1	<3	p-27/2	3-10	starosadka	<3	<3
p-12/4	70-80	bottom	<3	<3	p-27/3	30-40	karatuz	<3	<3
p-13/1	0-5	novosadka	<3	<3	p-27/4	50-60	bottom	<3	<3
p-13/2	5-10	starosadka	<3	<3	p-28/1	0-3	novosadka	<3	<3
p-13/3	40-60	bottom	<3	3±1	p-28/2	3-10	starosadka	<3	<3
p-14/1	0-10	novosadka	<3	<3	p-28/3	30-50	karatuz	<3	3±1
p-14/2	10-15	starosadka	50±5	<3	p-28/4	70-80	bottom	<3	<3
p-14/3	15-20	karatuz	<3	4±1	p-29/1	0-10	novosadka	<3	<3
p-14/4	60-70	bottom	<3	<3	p-29/2	10-20	starosadka	<3	3±1
p-15/1	0-10	novosadka	10±1	5±1	p-29/3	30-40	karatuz	<3	3±1
p-15/2	10-20	starosadka	6±1	6±1	p-29/4	40-50	bottom	<3	3±1
p-15/3	20-30	karatuz	<3	<3	p-30/1	0-3	novosadka	<3	<3
p-15/4	40-50	bottom	<3	4±1	p-30/2	10-30	karatuz	<3	<3
p-16/1	0-3	novosadka	<3	<3	p-30/3	80-100	bottom s	<3	<3

The results of laboratory investigations provided us with the distribution pattern for specific activity of ^{241}Am and ^{137}Cs in the upper surface layer (0-5 cm) on the lake and in the adjacent area. Figure 4 shows a schematic map of distribution of artificial radionuclides ^{137}Cs and ^{241}Am in the surface layer (0-5 cm).

The most contaminated areas, as it was expected, are the areas close to the "Experimental field". The character of ^{241}Am and ^{137}Cs distributions is similar. The map of their distributions looks like a mosaic with no contamination on the territory of the lake.

It was established that the character of ^{241}Am distribution in the profile of the salt stratum was slightly different from the character of ^{137}Cs distribution. Minimal concentration of ^{241}Am was registered in the novosadka layer and maximal – in the karatuz layer. Minimal concentration of ^{137}Cs was registered in bottom sediments, the lowest layer in the vertical salt profile.

In order to analyze the obtained data, the results of Table 3 are presented in the form of a histogram (Figure 5). To construct the histogram we used the ratios of the specific activity numerical values to the total number of measurements depending on the layer depth.



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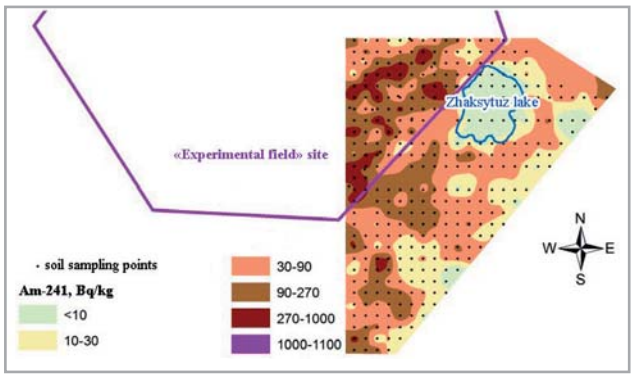


b)

Figure 4. A schematic map of ^{137}Cs (a) and ^{241}Am (b) distribution in the surface layer

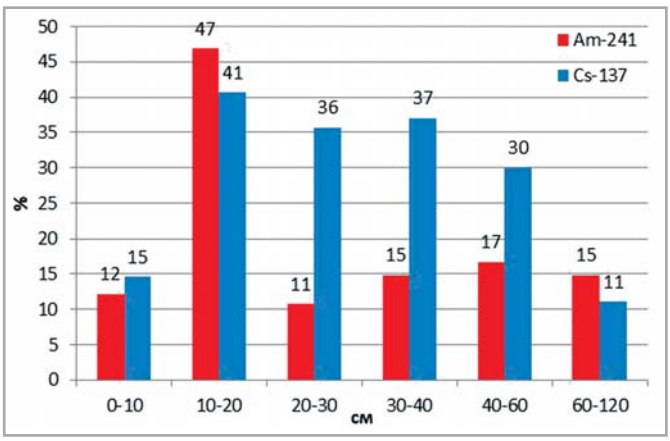


Figure 5. Occurrence frequency of ^{241}Am and ^{137}Cs numerical values for different depth intervals

The histogram shows the presence of artificial radionuclides along the whole depth of the layer. Most often numerical values of ^{241}Am are registered in the layer 10-20 cm; ^{137}Cs is mainly distributed in the layer 10 – 60 cm.

Such distribution of radionuclides can be explained by the following factors:

1. Different migration abilities of ^{241}Am and ^{137}Cs.
2. Mechanisms of formation of radiation contamination.

2.3. Determination of radionuclide forms in deposits

The results of laboratory analyses are presented in Table 4.

Table 4.

Results of gamma-spectrometric measurements of liquid and solid phases of samples of the salt strata

Sampling point	Specific activity of artificial radionuclides, Bq/kg			
	Filtrate		Precipitate	
	^{241}Am	^{137}Cs	^{241}Am	^{137}Cs
5/4	<2	<4	3±1	9±3
14/2	<2	<4	180±20	18±2
15/1	<2	<4	27±3	6±1
18/2	<2	<4	85±9	22±2
20/2	<2	<4	25±2	55±5

An analysis of obtained data showed that in all cases radionuclide contamination was caused by the admixtures of contaminated soil, silts and bottom sediments presented in this experiment by the residue obtained after filtration of dissolved salt samples. Salt component of samples, which after dissolution turned into filtrate, did not have studied artificial radionuclides in its composition. ^{241}Am and ^{137}Cs activity in all samples was below the registration threshold of the equipment used.

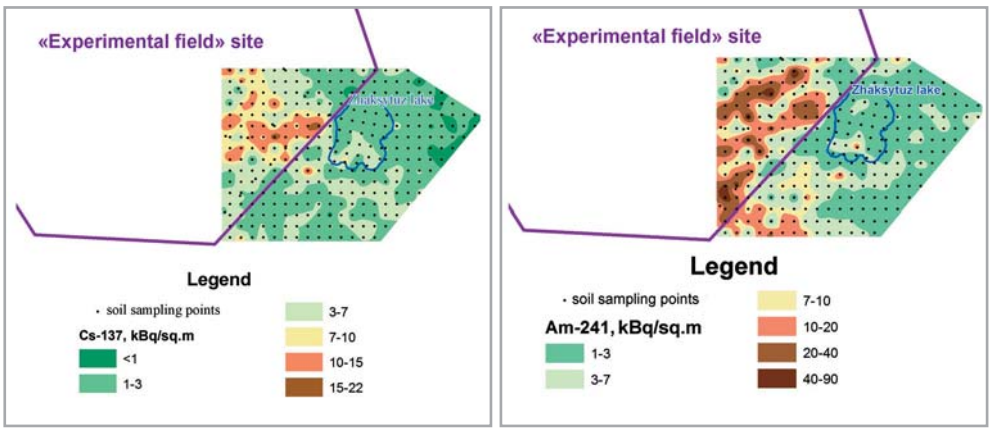
The above data were confirmed by the results of ^{90}Sr and $^{239+240}$Pu determination in salt samples. For the investigations we took stratified samples along the depth in points 26, 2, 1 and 6, where numerical values of specific activity of ^{241}Am or ^{137}Cs were registered. The results showed that ^{90}Sr and $^{239+240}$Pu concentrations in the dissoluble salt fraction were below the registration threshold of used equipment and techniques.

3. DISCUSSION OF THE RESULTS

The data on specific activity of radionuclides in the surface layer do not enable us to unambiguously claim that there is no radioactive contamination on the territory of the lake. This fact is related to the mechanisms of formation of the salt strata and to formation of radioactive contamination. In this case it will be more correct to consider areal contamination of the studied area, i.e. to determine amounts of radionclides along the depth of lithologic layer.

In order to determine amounts of radionclides we made sampling from all available data on ^{241}Am and ^{137}Cs distributions and assigned them into categories depending on the results. The obtained specific activity values were transformed into areal activity; for the

points with stratified samples the activity was summed up along the depth. The obtained data were used to construct a schematic map of the areal ^{137}Cs and ^{241}Am distribution in terms of kBq/m^2 (Figure 6).



a) b)

Figure 6. Areal distribution of ^{137}Cs(a) and ^{241}Am (b)

The figures above represent general areal contamination of the territory near south-eastern part of the "Experimental field". Several spots with increased values are marked in the figures. It should be noted that in such data representation the lake does not look like a "white" spot. The traces of radioactive contamination have their continuation in the lake. The activity of radionuclides in the lake and on the adjacent territory has close values. This result shows that contamination of the lake was formed as a result of passing of axes of the traces of ground nuclear tests on the test ground "Experimental field". Due to the processes of salt formation (growth of new salt layers), radionuclides went down to the lower layers.

CONCLUSION

Radioecological investigation of the deposit area has shown that the present-day contamination of the lake is caused by artificial radionuclides ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+240}Pu$. As over 50 years has passed since the last nuclear test, and salt is forming continuously, the surface layer does not contain artificial radionuclides. The main part of the radionuclide contamination is contained in the middle layer of the salt deposit, which shows natural vertical redistribution of radionuclides in depth. The fact that the concentration of ^{137}Cs and ^{241}Am in bottom sediments is lower than in the starosadka and karatuz only indicates that the process of deepening of radionuclides is not over yet.

It has been established that radioactive contamination of the salt strata is caused by the presence in salt of soil particles contaminated by artificial radionuclides and the level of contamination is practically the same as that on the adjacent territory, which is indicative of the same source and mechanism of formation of contamination. Specific activity of artificial radionuclides in the salt is lower than the detection level of used equipment.

At present no significant variations in the radiation situation to the worse due to secondary transfer, migration, etc. are observed.

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ЖАҚСЫТҰЗ АСТҰЗЫ КЕНОРНЫНЫҢ АУМАҒЫНДА РАДИОАКТИВТІ ЛАСТАНУДЫҢ ҚАЛЫПТАСУ ЕРЕКШЕЛІГІ

Айдарханов А.О., Лукашенко С.Н., Ляхова О.Н.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Мақалада, бұрынғы Семей сынақ полигоны (ССП) аумағындағы «Тәжірибе даласы» сынақ алаңының шекарасында орналасқан «Жақсытұз» астұзы кенорнының аумағына жасалған радиоэкологиялық зерттеу нәтижелері келтірілген. Кенорнының айрықша ерекшелігі, өнімді тұзды қатпардың түзілу механизмі болып табылады, оның қалыптасуы үздіксіз сипатта. Осылайша, 50 жыл бұрын ядролық сынақтардың салдарынан радиоактивті ластануға ұшыраған көлдің беткі қабаты, қазіргі уақытта жаңадан түзілген тұзды қатпардың терең қабатында жатыр. Техногенді радионуклидтермен негізгі беткі радиоактивті ластану, кенорнының жағалауындағы

құмдақ топырақта шоғырланған. Кенорнының өнімдік қатпарында техногенді радионуклидтердің қомақты түрде шоғырлануы анықталған жоқ.

Кілт сөздер: «Жақсытұз» тұз кенорны, Семей сынақ полигоны, радиоактивті ластану, радионуклидтер, алаңдық ластану.

ОСОБЕННОСТИ ФОРМИРОВАНИЯ РАДИОАКТИВНОГО ЗАГРЯЗНЕНИЯ ТЕРРИТОРИИ МЕСТОРОЖДЕНИЯ ПОВАРЕННОЙ СОЛИ ЖАКСЫТУЗ

Айдарханов А.О., Лукашенко С.Н., Ляхова О.Н.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В статье приведены результаты радиоэкологических исследований территории месторождения поваренной соли «Жаксытуз», расположенного у границы испытательной площадки «Опытное поле» бывшего Семипалатинского испытательного полигона (СИП). Отличительной особенностью месторождения является механизм образования продуктивного соляного пласта, формирование которого носит непрерывный характер. Таким образом, поверхность озера, подвергшаяся радиоактивному загрязнению в результате выпадений от ядерных испытаний порядка 50 лет назад, в настоящее время находится глубоко под вновь образовавшимся соляным слоем. Установлено, что основное поверхностное радиоактивное загрязнение техногенным радионуклидами сосредоточено в почвогрунтах береговой линии месторождения. В продуктивном пласте месторождения наличия значимых концентраций техногенных радионуклидов не выявлено.

Ключевые слова: месторождение соли «Жаксытуз», Семипалатинский испытательный полигон, радиоактивное загрязнение, радионуклиды, площадное загрязнение.

УДК 577.4: 551.578.46:504.064:546.11.02.3

TRITIUM CONTENT IN THE SNOWPACK IN SETTLEMENTS ADJACENT TO STS

Turchenko D.V., Lukashenko S.N., Aidarkhanov A.O., Lyakhova O.N.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

The paper presents the study of tritium in the snow cover in the large settlements adjacent to the territory of STS. Quantitative data on the content of tritium in snow near "Degelen" site and in the residential areas were obtained. The survey in the city Kurchatov, Kaynar and Sarzhal towns did not receive numerical concentrations of tritium in the snowpack. Outside the "Degelen" site limits, in the south and south-east, the concentrations of tritium do not exceed the detection limit of 11-16 Bq/kg.

Keywords: river bed water, tritium, snow cover, STS, migration of tritium, surface layer of snow, near-the-ground layer of the snow cover.

INTRODUCTION

At present, on the territory of the STS there are areas with water bodies that have high tritium concentration in surface and near-the-surface water [1]. Components of this ecosystem (vegetation, atmosphere and ground air) are also contaminated with tritium. It is supposed that tritium has high migration capabilities in ecosystem components and can proliferate by air from contaminated areas and therefore provide negative impact in the ambient air. Thus, it is important to evaluate transfer of tritium by air beyond the borders of STS in direction of populated areas like town of Kurchatov, villages Sarjal and Kainar located to the north and south of STS.

To evaluate the impact of tritium in the air of test sites "Balapan" and "Degelen", it is required to identify its possible migration routes in direction of populated areas beyond STS border.

The objective of this work is to get quantitative data on tritium concentrations in the snow cover at the populated areas adjacent to the STS border and near the STS testing grounds.

Main purposes of this work were:

- study of tritium concentrations in the snow cover in populated communities;
- study of tritium concentrations in vicinity of "Degelen" test site.

1. AREAS AND METHODS OF RESEARCH

The biggest populated communities in vicinity of STS were selected for the study. Figure 1 shows the location of these communities near the STS and research areas on the territory of STS.

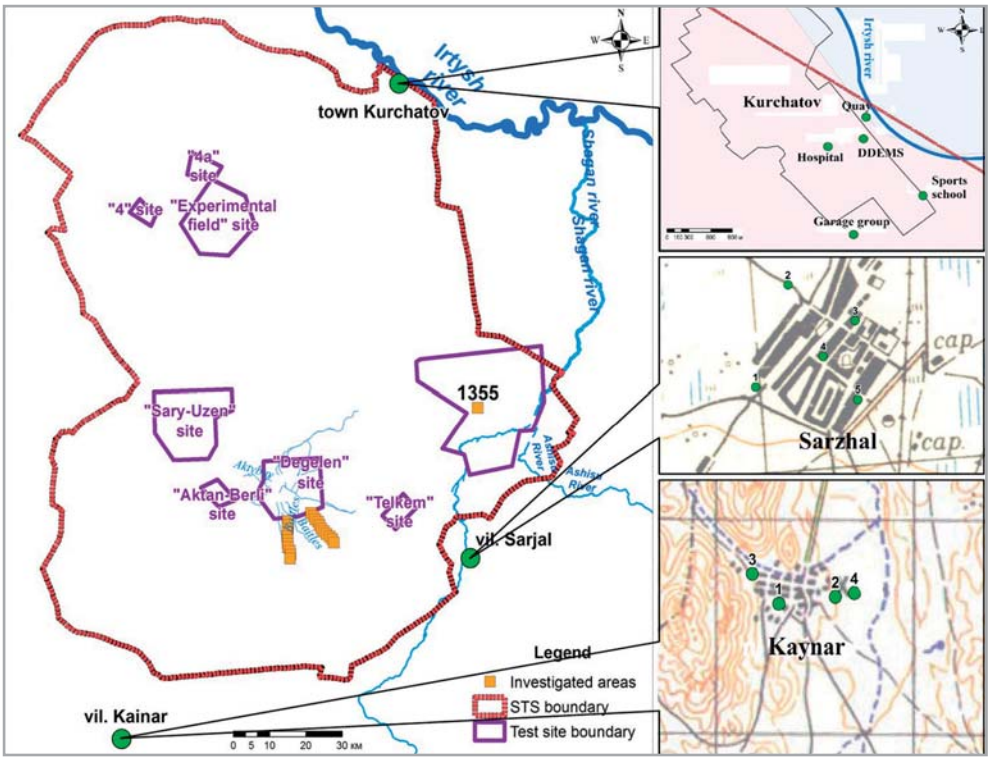

Figure 1. Location of research areas at STS and in the population communities adjacent to STS; sampling locations map: a) town Kurchatov, b) vil. Sarjal, c) vil. Kaynar, d) "background areas" of STS.

In the town of Kurchatov (Figure 1, a), samples of snow cover were collected through the whole winter period of 2011 and sampling locations covered the whole territory of Kurchatov (hospital, garages, children's sport school and river banking). In 2012 snow samples were collected only on the territory of the Institute (location of the Department of the monitoring systems development for environment – DMSDE). In villages Sarjal and Kainar (Figure 1, b and c) snow cover samples were collected only in March 2012 and sampling locations were evenly distributed over the territory of each village.

To determine tritium concentrations in the snow cover beyond the "Degelen" test site in southern and south-eastern directions (in direction to villages Kainar and Sarjal), 2 research profiles were made (Figure 1, d). Length of each profile (path) was 10 km with spacing between sampling locations 1 km. Snow samples were collected in March 2012 as it was supposed for maximum tritium accumulation in the snow cover during the winter.

Snow cover was sampled by layers 0-10 cm and 10-20 cm. In cases when total snow cover thickness was over 20 cm then it was sampled 0-10 cm and then for the whole depth up to underlying surface. Snow cover thickness was measured using measuring ruler.

To determine tritium concentrations, snow samples were placed into the plastic bag and then melted. Then the samples were put into 20 ml plastic test tube. To remove mechani-

cal solids the "Blue ribbon" filters were used. Filtered sample then was put into 20 ml plastic tank and scintillation solution was added in the proportion 3:12 ml.

To determine specific activity of tritium in snow samples, the liquid scintillation spectrometer TriCarb 2900 TR was used along with the standard measurement technique. [3].

2. RESULTS AND DISCUSSION

2.1. Study of tritium contents in the snow cover of populated areas

Table 1 reports on tritium analyses in the snow cover on the territory of Kurchatov city for the period 2011-2012.

Table 1.

Tritium concentration in the snow of Kurchatov city

Sampling period	Snow layer	Tritium specific activity, Bq/kg				
		DMSDE location	Children's sport school	Garage area	Hospital	River banking
February 2011	surface		<13	<13	<14	<14
March 2011	surface		<13	<13	<14	<13
	underlying			<13		<15
December 2011	surface	<12				
January 2012	surface	<12				
February 2012	surface	<12				
March 2012	surface	<12				
	underlying	<12				

Table 2 shows the results of tritium determination in the snow cover on the territory of Sarjal and Kainar villages.

Table 2.

Tritium concentration in the snow of Sarzhal and Kainar villages

Area	Snow layer	Tritium specific activity, Bq/kg				
		1	2	3	4	5
Sarzhal	surface	<12	<12	<13	<12	<13
	underlying	<12	<12	<13	<12	<12
Kainar	surface	<11	<12	<12	<13	
	underlying	<12	<13	<13	<12	

During the whole period of research (from 2011 to 2012) no tritium concentrations were detected exceeding detection limit of 12-16 Bq\kg on the territory of the biggest population communities. This means that there is no tritium in the air of Kurchatov city and villages Sarjal and Kainar: STS does not provide negative impact on these communities in terms of tritium.

2.2. Tritium studies in vicinity of "Degelen" site

Table 3 shows research results on tritium concentrations in the areas to the south and to the south-east from the "Degelen" test site.

Table 3.

Tritium concentration in the snow beyond the borders of "Degelen" site

Direction from "Degelen"	Snow layer	Distance from the border of "Degelen", km										
		0	1	2	3	4	5	6	7	8	9	10
		Tritium specific activity, Bq/kg										
South	surface	<12	<13	<12	<12	<12	<12	<11	<11	<12	<13	<11
	underlying	<12	<12	<12	<12	<11	<12		<11	<12	<11	
South-east	surface	<12	<12	<16	<12	<12	<12	<12	<12	<12	<11	<11
	underlying		<11	<11			<12	<12	<12		<11	<12

As it is seen from the data above, there is no tritium in the snow cover at the distance 10 km from the "Degelen" site in the southern and south-eastern directions. Even close to the border of "Degelen", tritium concentration was within the detection limit of 11-16 Bq\kg.

3. DISCUSSION OF RESULTS

No tritium was detected in the town of Kurchatov and villages Sarzhal and Kainar. In the whole snow cover, tritium concentration did not exceed the detection limit of 12-16 Bq\kg. In southern and southeastern directions from "Degelen" site towards the population communities, tritium concentrations also did not exceed the detection limit of 11-16 Bq\kg. This means that in the nearest proximity to "Degelen" site tritium is diluted by air masses and does not proliferate by the air beyond the site borders.

During the whole winter season snow is accumulated and compacted. Along with this, tritium is accumulated in the upper snow layer from the ambient air and in the near-the-ground layer – from underlying surface. This snow cover is an integral indicator of contamination in the air and in underlying surface.

CONCLUSIONS

Quantitative data was received on tritium concentration in the snow cover of populated areas adjacent to the STS territory and near the "Dagelen" site. No tritium was detected in the snow cover in the villages. Beyond the border of the "Degelen" site and in the populated areas, tritium concentration in the snow cover did not exceed 11-16 Bq\kg. Thus tritium in the ambient air is diluted and does not reach territory of populated areas like town of Kurchatov and villages Srazhal and Kainar.

The authors express thanks to the members of the Institute of radiation safety and ecology Muliankin V.A., Yesimbekov A. for assistance in expedition, Lyakhova O.N. and the Group of general chemistry DMSDE for handling and analyzing snow samples.

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ССП АУМАҒЫНА ЖАҚЫН ЖАТҚАН ЕЛДІ-МЕКЕНДЕРДІҢ ҚАР ЖАМЫЛҒЫСЫНДАҒЫ ТРИТИЙДІҢ ҚҰРАМЫН ЗЕРТТЕУ

Турченко Д.В., Лукашенко С.Н., Айдарханов А.О., Ляхова О.Н.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Бұл мақалада, ССП аумағына жақын жатқан ірі елді-мекендердің аумақтарындағы қар жамылғысында тритийдің құрамын зерттеу нәтижелері келтірілген. «Дегелең» сынақ алаңына жақын жердегі және елді-мекендердің аумақтарындағы қар жамылғысында тритийдің құрамы бойынша мөлшерлік деректер алынды. Зерттеу кезеңінде, Курчатов қаласы, Саржал және Қайнар ауылдары елді-мекендерінің аумағындағы қар жамылғысындағы тритий шоғырлануының мөлшері алынған жоқ. «Дегелең» сынақ алаңының шекарасында, оңтүстік және оңтүстік-шығыс бағытта, тритийдің шоғырлануы – 11-16 Бк/кг анықтау шегінен асқан жоқ.

Кілт сөздер: арнадағы су, тритий, қар жамылғысы, ССП, тритийдің жылыстауы, қар жамылғысының үстіңгі қабаты, қар жамылғысының беткі қабаты.

ИЗУЧЕНИЕ СОДЕРЖАНИЯ ТРИТИЯ В СНЕЖНОМ ПОКРОВЕ НАСЕЛЕННЫХ ПУНКТОВ, ПРИЛЕГАЮЩИХ К ТЕРРИТОРИИ СИП

Турченко Д.В., Лукашенко С.Н., Айдарханов А.О., Ляхова О.Н.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В работе представлены результаты исследования содержания трития в снежном покрове на территории крупных населенных пунктов прилегающих к территории СИП. Получены количественные данные по содержанию трития в снежном покрове вблизи испытательной площадки «Дегелен» и на территории населенных пунктов. В период обследования на территории населенных пунктов города Курчатов, поселков Саржал и Кайнар не получено численных концентраций трития в снежном покрове. За пределами границы испытательной площадки «Дегелен», в южном и юго-восточном направлении, концентрация трития не превышала предел обнаружения – 11–16 Бк/кг.

Ключевые слова: русловая вода, тритий, снежный покров, СИП, миграция трития, поверхностный слой снежного покрова, приземный слой снежного покрова.

УДК 504.4.054:577.4:546.11.02.3

TRITIUM CONTENT IN THE SNOWPACK AT THE SHAGAN RIVER

Turchenko D.V., Lukashenko S.N., Aidarkhanov A.O., Lyakhova O.N.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

This paper reports on a study of tritium in the snow cover on the Shagan River. Spatial distribution of tritium in the snow was investigated relatively to Shagan riverbed. We revealed a regularity that the maximum concentrations of tritium are located in the center of the bed and reached 15,000 Bq/kg. Outside the bed, tritium concentrations reach 20 to 150 Bq/kg. Mechanisms of tritium inflow in the snow cover were identified; the most significant tritium inflow mechanism outside the channel is the condensation of tritium-containing water vapor on the particles of snow at the time of precipitations.

Keywords: river bed water, ground water, tritium, snowpack, Shagan River, STS, migration of radionuclides, ice cover, surface layer of snow, near-the-ground layer of snow, emanation of tritium from the soil.

INTRODUCTION

Tritium studies in the snow cover at the "Degelen" [1] site showed that close to the brook stream that has high tritium concentration in the water the snow has also high tritium concentrations in the surface layer of snow and in near-the-ground layer. In all researched areas tritium concentration in the near-the-ground layer is higher than in surface layer. Beyond the main river bed, tritium concentration in the snowpack drops to the background levels. As it was proven at the "Degelen" site, the main mechanism of tritium transfer to the snowpack is emanation from underlying surface.

At the Shagan River there are areas with anomaly-high tritium concentrations in the surface and ground water [2]. In the same areas, high tritium concentrations are detected in the ecosystem components (vegetation, surface and atmospheric air). In the areas of underground nuclear tests there is tritium inflow to the snowpack from the underlying surface [3]. Results of previous studies showed that snow is an integral indicator of contamination with tritium for air and soil environment.

The purpose of this work is to study the impact of the transfer mechanisms on the spatial distribution of tritium in snowpack and to evaluate background tritium concentrations at the Shagan River.

The main tasks for this work were:

- Research of spatial distribution of tritium in the snowpack *along* the Shagan riverbed (axial profiles);
- Research of tritium spatial distribution in the snowpack over the area *perpendicular* the Shagan riverbed (cross-axis profiles);
- To determine background tritium concentrations in the snowpack along the Shagan riverbed.

1. OBJECTS AND METHODS OF RESEARCH

As the research object, a 9-15 km long area was selected of the main riverbed of the Shagan River from the "Atomic lake" (hereinafter "AL"). Field work was done in two stages:

- in December evaluation of background tritium concentrations was conducted in fresh snowpack;
- in February and March evaluation was conducted of tritium concentrations for the whole winter season. During the whole winter season the snowpack total thickness changed depending on the terrain. On the hills and elevations snow thickness was about 5-10 cm and in riverbeds and lowlands 20-30 cm.

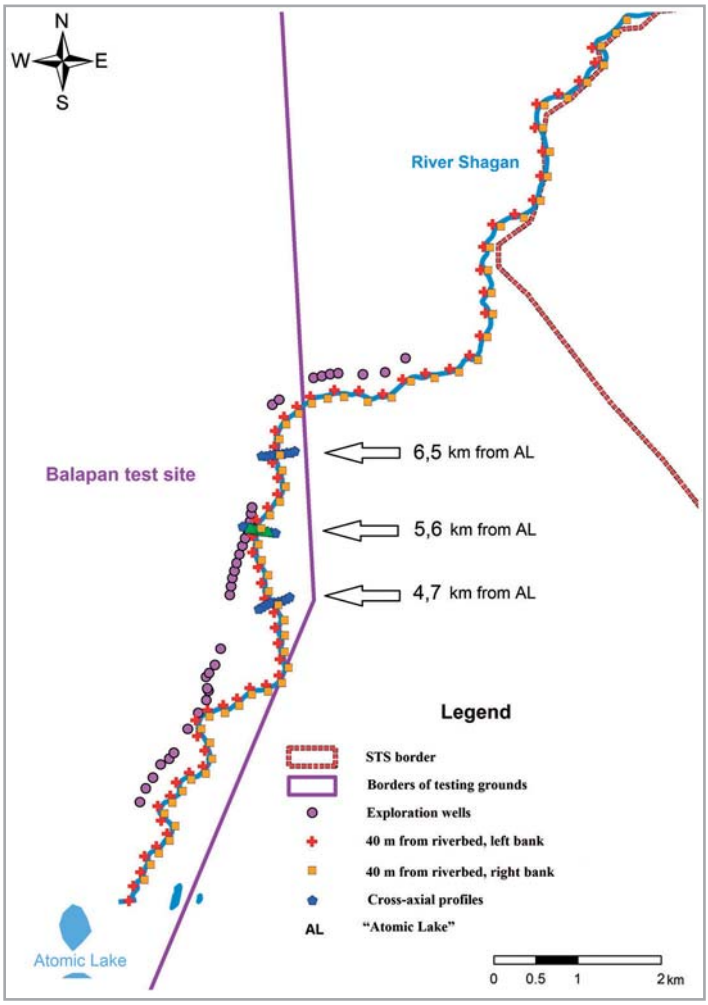

Figure 1. Location of sampling areas at the Shagan River

Figure 1 shows the location of axial and cross-axis profiles at the Shagan River. To study spatial distribution of tritium in snowpack *along* the Shagan riverbed, two *axial* profiles were laid at 10-15 km areas from "AL" (40 m from the riverbed along the right bank and 40 m from the riverbed along the left bank). Distance between the locations in each axial profile was 200-300 m. Showpack samples were taken on the axial profile on the right bank in February 2012 and on the left bank in March 2012. Received data was used to evaluate nature of spatial distribution of tritium in snowpack across the area perpendicularly to the main riverbed of Shagan River.

To study spatial distributin of tritium in snowpack on the areas with high tritium concentrations (4.7 km, 5.6 km and 6.5 km from "AL") 3 research profiles were laid *perpendicular* to the Shagan riverbed (Figure 1). Center of the profile was located in the center of the Shagan riverbed and distance between sampling locations in the profile was 50 m. The research profiles were located on the right and left sides of the Shagan River. For more detailed study of spatial tritium distribution in snow at the profile 5.6 km, one more snow sampling was done in March 2012 with the sampling distance 20 m.

In December 2011 a 9 km-long *axial* research profile was installed from "AL" to evaluate background concentrations of tritium in snowpack at the distance not less than 150 m away from the Shagan riverbed. Distance between sampling points was 200-300 m. Snowpack sampling was done by layer to the depth 0-10 cm and 10-20 cm. In cases when total snowpack depth was less than 20 cm, sampling was done to the depth 0-10 cm (surface layer) and to the remaining depth (near-the-ground layer). If total snowpack depth was 30 cm, then surface, intermediate and near-the-ground layers were sampled. Showpack depth was measured using measuring ruler.

The snowpack samples were put into plastic bag and melted to determine tritium concentration. Then the samples were put into the 20 ml plastic test-tube. Melted snow samples were filtered using filers "Blue ribbon" to remove mechanical solids. Then filtered sample was put into the 20 ml plastic container and scintillation cocktail was added in the proportion 3:12 ml. Specific activity of tritium in the snow samples was determined using liquid scintillation spectrometer Tri-Carb 2900 TR employing standard method [4].

2. RESULTSS

2.1. Tudy of spatial distribution of tritium in snowpack along the main riverbed of Shagan river

Figure 2 shows spatial distribution of tritium in the snowpack at studied areas along the riverbed of Shagan River. To plot the graph of spatial distribution of tritium, in the cases when tritium concentrations were below the detection limit of 12-13 Bq\kg, the value of the detection limit was taken.

As it is seen from the results (Figure 2), along the 15 kilometer area from the "Atomic lake" along the left and right banks of Shagan riverbed there is an area (from 4.7 to 6.5 km from "AL") with anomaly high tritium concentrations in the snowpack reaching 5,500 Bq\kg. Increased tritium concentrations are detected on the right and left banks of the Shagan River. Also it is to be mentioned that in all cases tritium concentration in the surface layer of snow was higher than in near-the-ground layer.

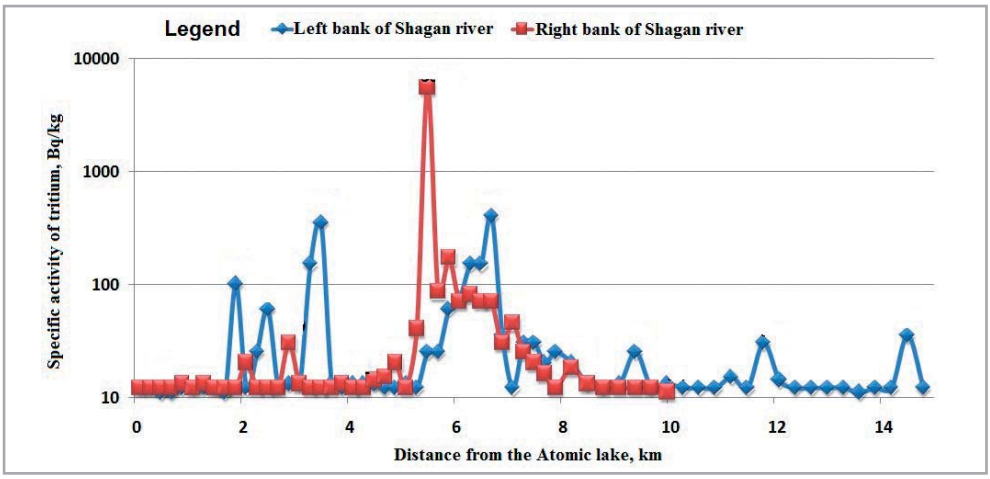

Figure 2. Spatial distribution of tritium along the riverbed of Shagan river

Analyzing the results it was determined that at the distance 40 m from the Shagan river, maximum concentrations are prevailing at the area from 4.7 to 6.5 km from the "AL" and reach 5,500 Bq\kg. At this area tritium concentration is higher in the surface layer of snow than in near-the-ground layer. It can be assumed that tritium comes by atmospheric way from the Shagan River in the result of condensation of tritium-containing water vapor on snow particles.

2.2. Study of spatial tritium distribution in the snowpack perpendicular to the main riverbed of the Shagan River

Figure 3 shows spatial distribution of tritium in perpendicular to the riverbed of the Shagan River at the area (from 4.7 to 6.5 km) with anomaly high tritium concentration in the snowpack.

Along all research profiles, maximum tritium concentrations in the snowpack prevail in the ice cover and reach 5,000-15,000 Bq\kg. It must be mentioned that beyond the main riverbed tritium concentration in the surface layer of snow is higher than in near-the-ground layer. Presumably, tritium comes to the snowpack at this area from atmosphere. At the distance 100-150 m from the Shagan River tritium concentration drops to the background levels.

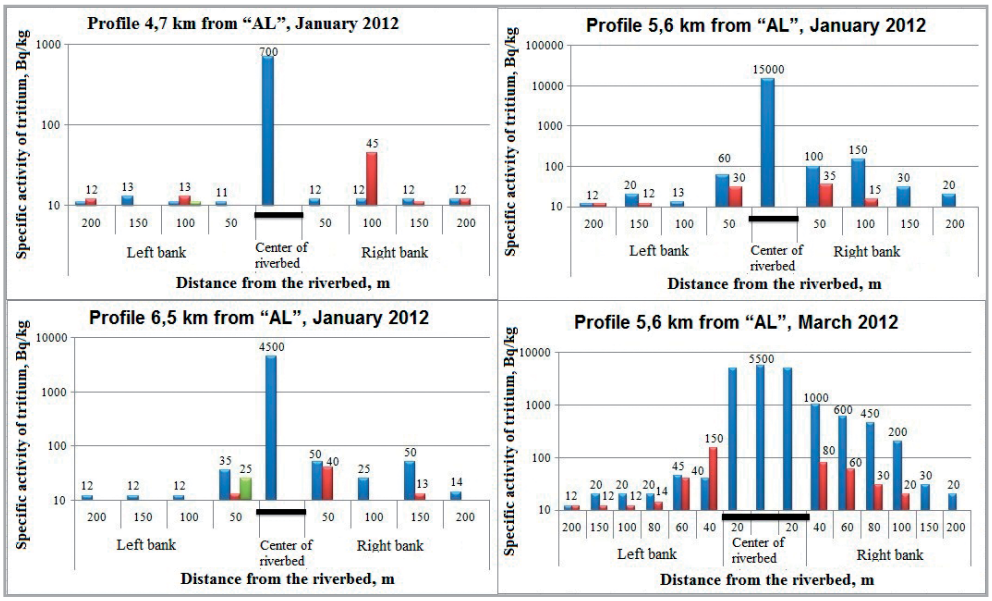

Figure 3. Spatial distribution of tritium in the snowpack at the Shagan River

2.3. Determination of tritium background concentrations in December 2011

Figure 4 describes spatial tritium distribution in the snowpack and ground water at the distance 150-300 m along the riverbed of the Shagan River.

Average tritium concentrations in the snowpack did not exceed the detection limit of 13 Bq\kg and in some cases higher tritium concentrations reaching 25-40 Bq\kg were detected in the snow. Presumably, higher tritium concentration in the snowpack is related to shallow depth of ground water aquifers that have high tritium concentration (Figure 4).

Along the whole 9-kilometer area from the "AL", tritium concentration in ground water ranges from 1,000 to 40,000 Bq\kg. Depth of ground water aquifers in the exploration wells varies from 3.6 to 5.4 m [5]. Thus, using the received data it is impossible to estimate accurately influence of specific mechanism of tritium entry into snowpack. It can be assumed that at this area there is influence of several entry mechanisms on tritium into snowpack: emanation of tritium from soil and entry from atmosphere.

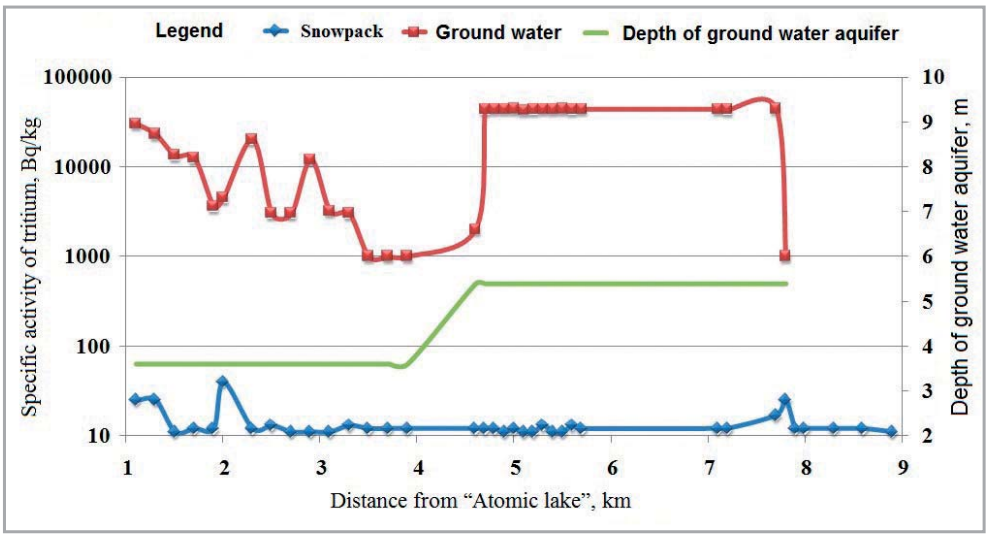

Figure 4. Comparison data on tritium concentration in snowpack and ground water

3. DISCUSSION OF RESULTS

Figure 5 shows roundup data on tritium concentration in the snowpack and riverbed water of the Shagan River at the 15 km area from "AL". The results show that along the whole 15 kilometer area from "AL" there is significant correlation between tritium concentration in riverbed water and the snowpack. This proves that main mechanism of tritium entry into the snowpack is condensation of tritium-containing water vapors on snow particles during atmospheric precipitation.

Figure 6 shows spatial distribution of tritium in the snowpack relative to all perpendicular research profiles. For each case (profile), tritium concentration is rated to the maximum value in the profile. Approximation curve at the Figure 6 shows nature of tritium contamination distribution relative to the riverbed of the Shagan River.

Obtained spatial distribution of tritium showed that maximum concentrations of tritium (5,000 Bq\kg) prevail in the center of the riverbed of the Shagan River and are limited by nullah. Beyond the riverbed, tritium concentration in the surface layer of snowpack is higher than in near-the-ground layer. This means that tritium came into the snowpack from atmosphere via wind transfer of snow from more contaminated parts of the riverbed. Along with this, at the distance of 100-150 m tritium concentration in all layers of snow decreases back to the background concentrations.

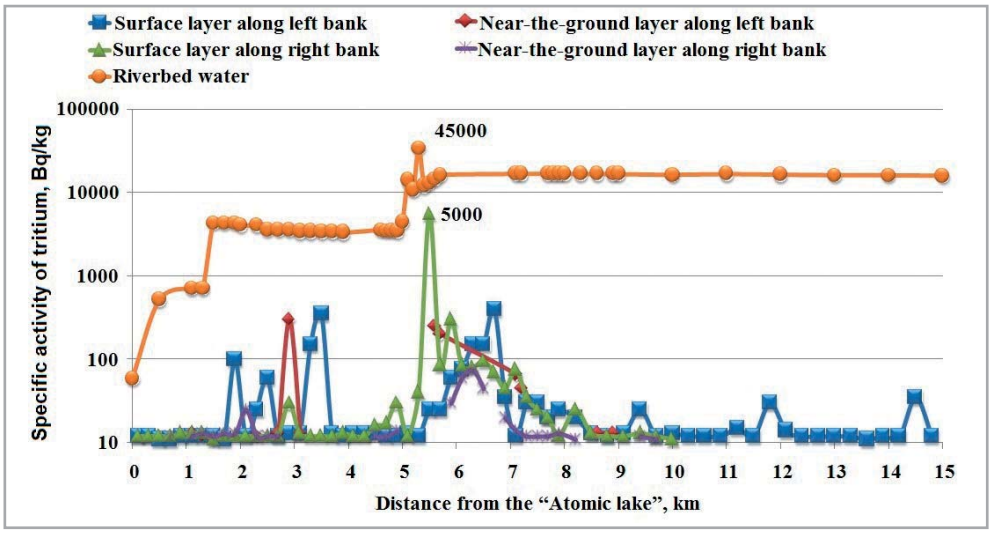

Figure 5. Comparison data on tritium concentration
in the snowpack and riverbed water at the Shagan River

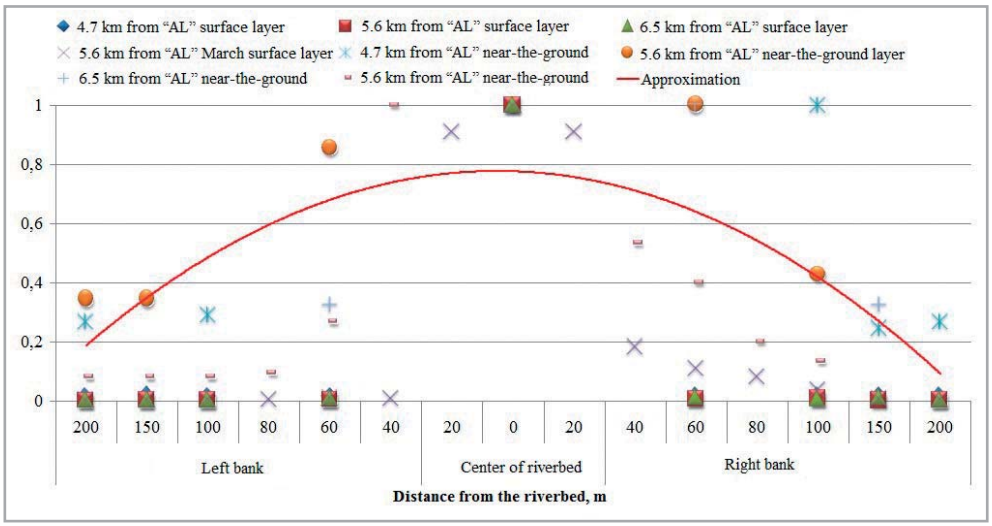

Figure 6. Spatial distribution of tritium perpendicular to the riverbed of the Shagan River

The ratio of tritium concentration in near-the-ground layer of snow to tritium concentration in surface layer shows influence of tritium-to-snowpack entry mechanisms. If the ratio is equal to 1 or more, then the main entry mechanism is emanation from soil, but if ratio is less than 1, then tritium enter the snowpack from atmosphere [6]. Figure 7 shows average ratios of tritium concentration in near-the-ground layer ($C_{near\text{-}the\text{-}ground}$) to tritium concentration in surface layer of snow ($C_{syrface}$) that are calculated for each area of STS. At all streams of

the "Degelen" site, the relation ratio is over 1 (from 1 to 14) what means that the main entry mechanism of tritium is emanation from soil and ice [6].

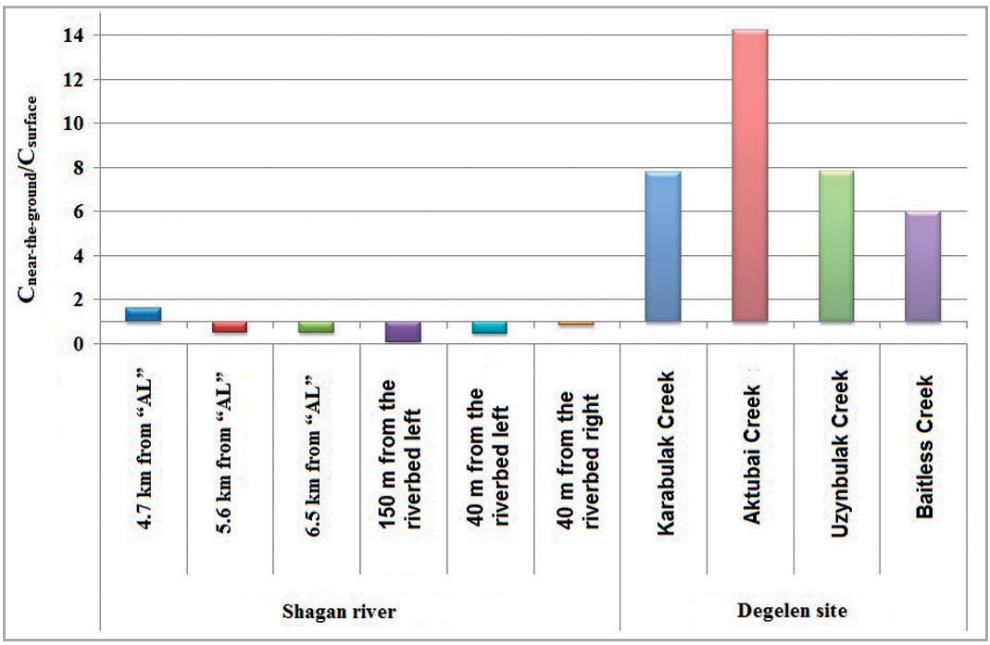

Figure 7. Spatial distribution of tritium in perpendicular to the riverbed of the Shagan river

At the river Shagan, average ratio $C_{near\text{-}the\text{-}ground}\backslash C_{surface}$ of snowpack is 0.65 what shows that tritium comes from atmosphere. In the riverbed of Shagan River at areas with high tritium concentration in water both entry mechanisms are in place: from atmosphere and emanation from soil. Beyond the main riverbed, tritium enters to snowpack from atmosphere in the result of evaporation and precipitation of tritium-containing water vapors on the snow particles during precipitation and packing.

CONCLUSIONS

Quantitative data was received on tritium concentration in the snowpack along the main riverbed of the Shagan River. At the distance from 1 to 15 km from "AL" there are several areas of the main riverbed that has high tritium concentration in the snowpack reaching 5,000 Bq\kg. Areas with high tritium concentration in the snowpack do match the areas with high tritium concentration in the river water.

Nature of spatial tritium distribution in the snowpack perpendicular to the main riverbed of the Shagan River shows that maximum tritium concentration is related to areas with ice within the riverbed (0-50 m). Beyond the main riverbed (50-200 m), tritium concentration decrease back to the background levels of 12-20 Bq\kg.

Within the main riverbed of the Shagan River, two main tritium entry mechanisms are verified: emanation from soil and ice and from atmosphere in the result of precipitation of

tritium-containing water vapors on snow particles during fallout. Also there is an assumption that in case of shallow ground water aquifers, tritium can enter the snowpack from ground water.

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ШАҒАН ӨЗЕНІНІҢ ҚАР ЖАМЫЛҒЫСЫНДАҒЫ ТРИТИЙДІҢ ҚҰРАМЫН ЗЕРТТЕУ

Турченко Д.В., Лукашенко С.Н., Айдарханов А.О., Ляхова О.Н.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Бұл жұмыста, Шаған өзенінің қар жамылғысындағы тритийдің құрамын зерттеу нәтижелері келтірілген. Шаған өзенінің арнасына қатысты қар жамылғысындағы тритийдің кеңістіктік таралуы зерттелді. Тритийдің максималды шоғырлануы арнаның орталығында орналасуына және 15000 Бк/кг-ға жетуіне қатысты заңдылық анықталды. Ағын судың арнасынан тыс жерде тритийдің құрамы 20-дан 150 Бк/кг-ға дейін жететіні анықталды. Тритийдің қар жамылғысына түсу механизмдері анықталды, арнадан тыс жерге тритийдің түсуінің маңыздырақ механизмі, атмосфералық жауын-шашындардың түсуі барысындағы қардың бөлшектеріндегі су буларының құрамындағы тритийдің конденсациясы болып табылады.

Кілт сөздер: арналық су, топырақасты суы, тритий, қар жамылғысы, Шаған өзені, ССП, радионуклидтердің жылыстауы, мұз жамылғысы, қар жамылғысының беткі қабаты, қар жамылғысының жербеткі қабаты, топырақтан тритийдің эманациялануы.

ИЗУЧЕНИЕ СОДЕРЖАНИЯ ТРИТИЯ В СНЕЖНОМ ПОКРОВЕ НАСЕЛЕННЫХ ПУНКТОВ, ПРИЛЕГАЮЩИХ К ТЕРРИТОРИИ СИП

Турченко Д.В., Лукашенко С.Н., Айдарханов А.О., Ляхова О.Н.

Институт радиационной безопасности и экологии НЯЦ РК, Курчатов, Казахстан

В работе представлены результаты исследования содержания трития в снежном покрове на территории крупных населенных пунктов прилегающих к территории СИП. Получены количественные данные по содержанию трития в снежном покрове вблизи испытательной площадки «Дегелен» и на территории населенных пунктов. В период обследования на территории населенных пунктов города Курчатов, поселков Саржал и Кайнар не получено численных концентраций трития в снежном покрове. За пределами границы испытательной площадки «Дегелен», в южном и юго-восточном направлении, концентрация трития не превышала предел обнаружения – 11-16 Бк/кг.

Ключевые слова: русловая вода, тритий, снежный покров, СИП, миграция трития, поверхностный слой снежного покрова, приземный слой снежного покрова.

УДК 577.4: 551.49:546.11.02.3:539.16

TRITIUM CONTENTS IN THE SNOW COVER AT THE "DEGELEN" SITE

Turchenko D.V., Lukashenko S.N., Aidarkhanov A.O., Lyakhova O.N.

Institute of Radiation Safety and Ecology NNC RK, Kurchatov, Kazakhstan

The paper reports on tritium contents in the snow cover on the waterways Karabulak, Uzynbulak and Baytles on the territory of the "Degelen" site. Maximum concentrations of tritium were found in the snow cover in March, they were revealed in the center of the channel, in the zones of ice cover of the underlying surface. Dynamics of tritium concentration in the snow cover during winter period was studied. Detailed information was obtained about the mechanisms of tritium inflow into the snow cover at various distances from the stream beds of Uzynbulak and Baytles.

Key words: ground water, tritium, snow cover, Uzynbulak, Karabulak, Baytles, STS, migration of radionuclides, ice cover, surface layer of snow, near-the-ground layer of snow, emanation of tritium from soil.

INTRODUCTION

The investigations of tritium concentration in the snow cover on the "Degelen" site [1] revealed an interrelation between tritium concentration in the water of the streams and tritium concentration in the snow cover. It was found out that the snow cover near the stream bed could have high tritium concentrations both in the near-the-ground and surface snow layers. As the distance from the stream bed in the perpendicular direction increased, the tritium concentration in the snow cover decreased to the background values. An assumption was made that within the main stream beds the major mechanism of tritium penetration into the snow cover was emanation from the underlying surface.

The earlier obtained data on the snow cover were used as a primary assessment of the scale of tritium contamination of the environment. The paper contained isolated data on spatial tritium distribution perpendicular to the beds of the Uzynbulak, Karabulak and Aktybay streams. A preliminary forecast of the variations in the dynamics of tritium concentrations within winter months was made, and background tritium concentrations in snow cover on the "Degelen" site were obtained. However, the data of that research were not sufficient to obtain a reliable picture of spatial tritium distribution and dynamics of variations in tritium concentration in the snow cover throughout the winter period.

The purpose of the research is to estimate the character of spatial tritium distribution and dynamics of variations in tritium concentration in the snow cover during the winter period.

1. OBJECTS AND METHODS OF INVESTIGATIONS

As the objects of investigations we chose the streams Uzynbulak, Karabulak and Baytles. Figure 1 shows location of the research areas on the "Degelen" site.

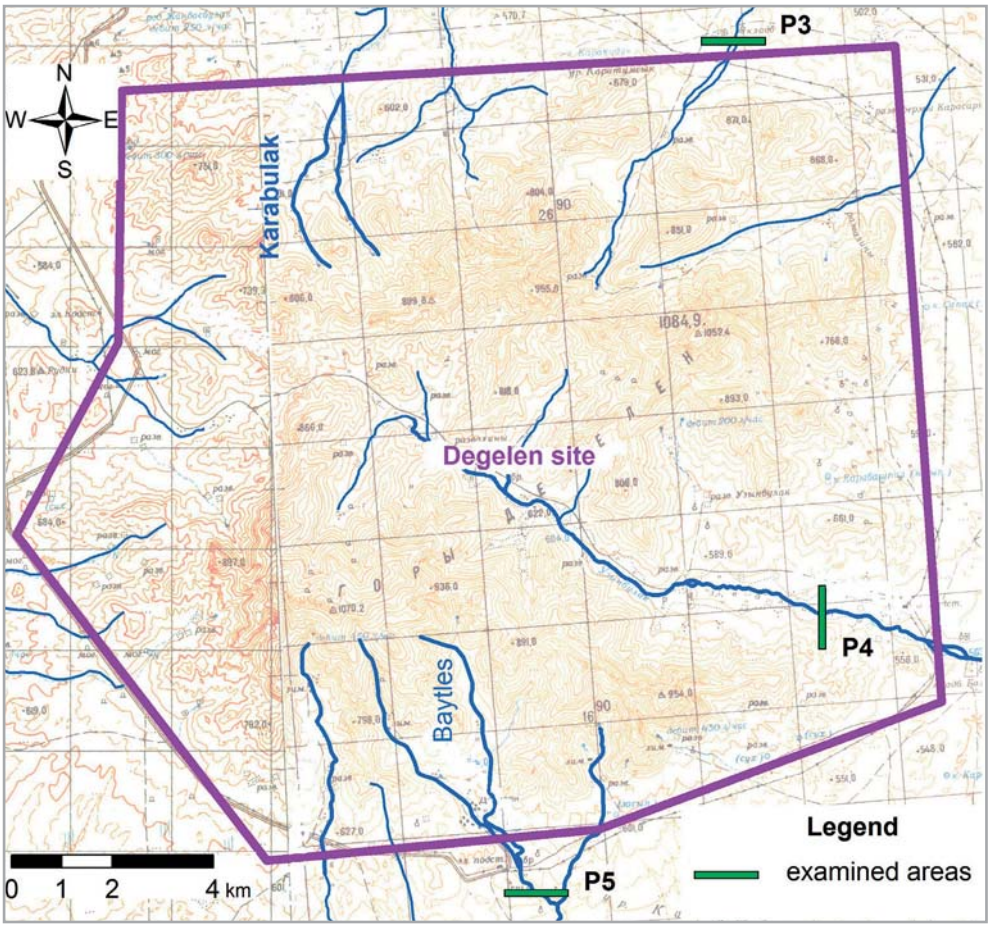

Figure 1. Location of examined areas on the "Degelen" site

The research work consisted of the following stages:

- Studying of spatial (areal) tritium distribution in various seasons of the year (monthly);
- Studying of dynamics in tritium concentration depending on the depth of the snow cover.

To study dynamics of spatial tritium distribution by area in the Uzynbulak, Karabulak and Baytles streams, research profiles were drilled perpendicularly to the main stream bed. The points of the research profile were located on the left and right banks of the stream bed. The center of the profile was located in the center of the stream bed, the distance between the sample points was 50 m. Snow samples in the snow cover were taken at depths 0-10 cm (surface layer), 10-20 cm (intermediate layer) and 20-30 cm (near-the-ground layer). Snow samples were gathered every month in the winter-spring period, from December to March. To study the dynamics in tritium concentration in-depth of the snow cover on the Uzynbulak

and Baytles streams 3 research areas were made. They were located:directly in the stream bed;at a distance of 50 m to the main stream bed;at a distance of 300 m or 800 m to the main stream bed.

The area of the examined territory was not more than 4m^2. For visual assessment of the snow cover layers, the upper snow layer was marked by the 0.1-0.3 cm sand layer (Figure 3). The snow samples were taken after hardening of the newly-fallen snow.To study the spatial tritium distribution over the area, the snow samples were gathered in layers at a depth of 0-10 cm and 10-20 cm. In rare cases, when the total snow cover was less than 20 cm, the snow samples were taken from the depth 0-10 cm and the remaining depth to the underlying surface. The thickness of the snow cover was measured by the measuring ruler.To study the dynamics of tritium distribution in the snow cover, the snow samples were gathered in layers; on the Uzynbulak stream three sampling depths were used: 0-10, 10-20 and 20-30 cm, on the Baytles stream the samples were taken from the depths – 0-1 cm (ice crust), 1-3 cm, 3-6 cm and 6-10 cm. The thickness of the snow cover was measured by the measuring ruler. To determine tritium concentration the snow samples were placed in polyethylene bags and melted to the liquid state. The obtained samples were placed in 20 ml plastic test-tubes. To remove mechanical admixtures the snow samples were filtered through fitters "Blue ribbon". The obtained filtered sample was placed in the 20 ml plastic cavity to which a scintillation liquid in proportion 3:12 ml was added.

Tritium specific activity in snow samples was determined according to a standard method using a liquid scintillation spectrometer TriCarb 2900 TR [2].

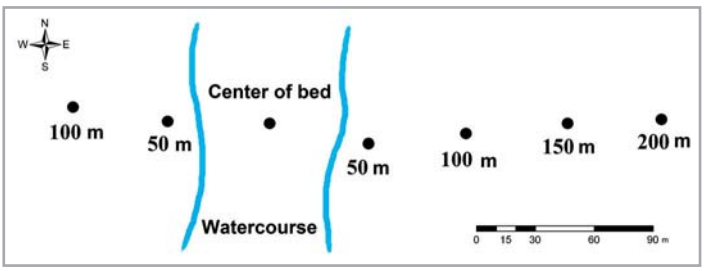

Figure 2. Points in the research profile

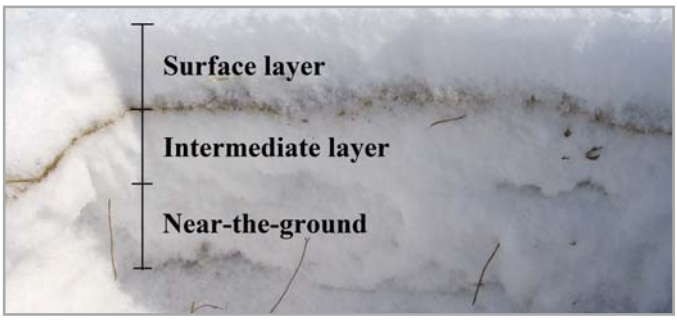

Figure 3. Snow cover layers

2. RESULTS

2.1. Spatial tritium distribution over the area

2.1.1. Karabulak stream

Figure 4 shows summarized data obtained earlier [1] and in 2012 characterizing spatial tritium distribution in the snow cover perpendicular to the Karabulak stream bed in the 2011-2012 winter period.

The obtained results show that in the same area the tritium concentration in snow layers increases with time. Maximal tritium concentrations in the snow cover were registered in the ice cover of the stream bed. Throughout the winter-spring period, the concentration of tritium in the near-the-ground snow was always greater than in the surface layer.

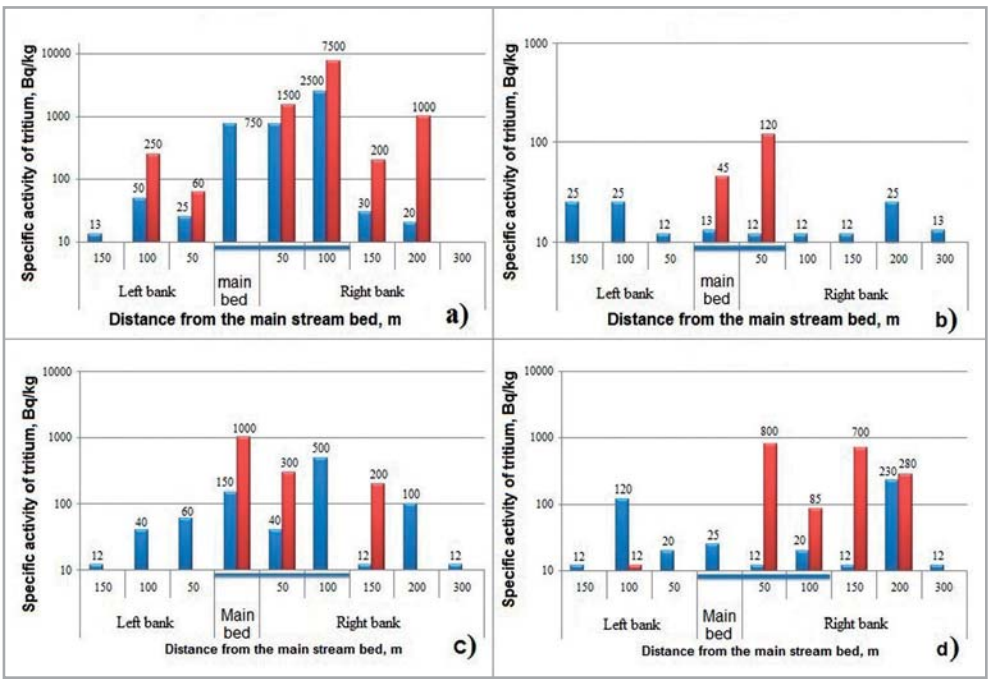

Figure 4. Spatial tritium distribution in the snow cover on the Karabulak stream in the 2011-2012 winter period: a) March 2011, b) December 2012, c) January 2012, d) March 2012.

2.1.2. Uzynbulak stream

Figure 5 shows the spatial tritium distribution perpendicular to the Uzynbulak stream. In this area the boundary of the ice cover changes with time. In December the snow cover does not exceed the width of 50 m and coves the entire surface of the stream. In January and February, the stream water goes out from the ice-hole on the surface of the ice cover, uniformly spreads over the surface, freezes and forms a larger surface of the ice cover of a

width of 75-100 m. In March, the snowmelt water contributes to underflooding of the main stream bed, and the boundary of the ice cover may become as wide as 200 m.

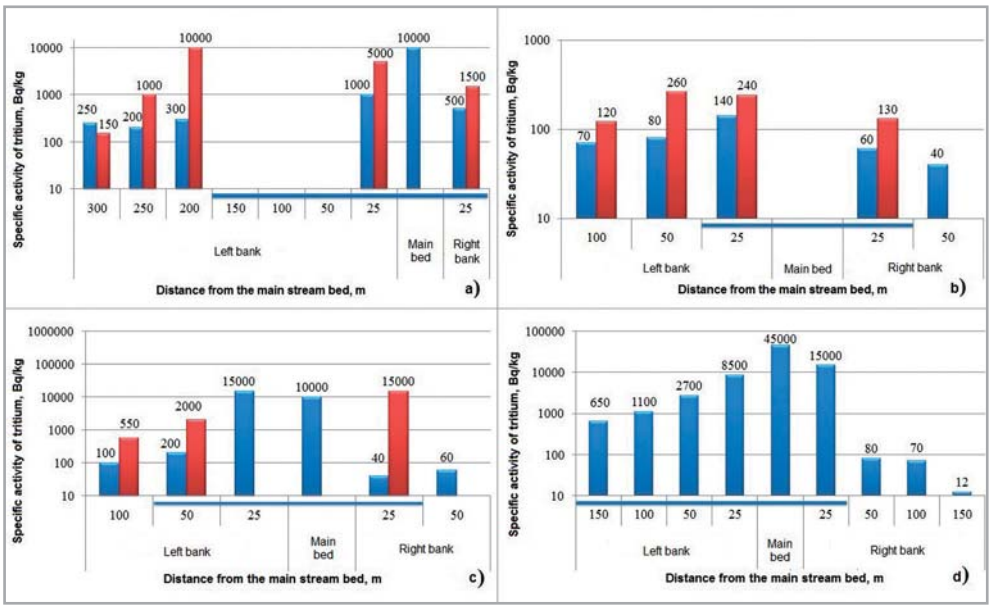

Figure 5. Spatial tritium distribution in the snow cover on the Uzynbulak stream in the 2011-2012 winter period: a) March 2011, b) December 2012, c) January 2012, d) March 2012.

From December 2011 to March 2012 the tritium concentration in snow layers increases. Maximal tritium concentrations in the snow cover were registered in the ice cover. In January (Figure 5 c) the tritium concentration the ice cover was 40,000-50,000 Bq/kg, in the snow cover it did not exceed 15,000 Bq/kg. As in the previous case, the tritium concentration in the near-the-ground snow layer was greater than in the surface layer.

2.1.3. Baytles stream

The width of the main stream bed and the ice cover during the winter did not exceed 50m. Figure 6 shows the spatial tritium distribution on to the Baytles stream. As in the two previous cases the maximal tritium concentrations prevail in the center of the main stream bed, in the ice-covered zones in the underlying surface. During the winter period the tritium concentrations in the near-the-ground snow layer are higher than in the surface layer.In the spring, the near-the-ground layer of the snow cover accumulates significant tritium concentrations, however, they do not exceed the tritium concentrations in the ice cover and surface water. During the winter the surface snow layer periodically changes, it means that during this period the tritium concentration in the upper snow layers can decrease and then increase again. Within the stream bed the tritium concentration may be as high as 40,000 Bq/kg, whereas beyond the stream bed the average tritium concentrations range from 60 to 250 Bq/kg.The obtained results confirm the earlier made assumption made on

tritium inflow to the snow cover from the underlying surface of ice or soil cover, i.e. the main mechanism of tritium inflow to the snow is its emanation from the underlying surface.

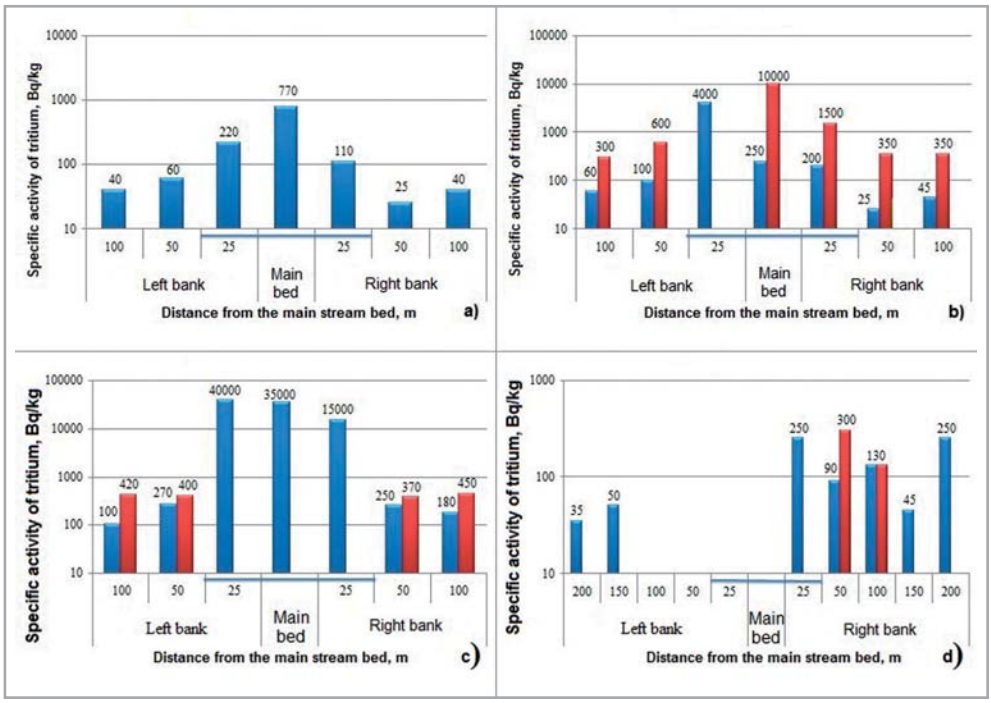

Figure 6. Spatial tritium distribution in the snow cover on the Baytles stream in the 2011-2012 winter period: a) December 2012, b) January 2012, c) February 2012, d) March 2012.

2.2. Investigation of tritium concentration dynamics in the snow cover

2.2.1. Uzynbulak stream

Minimal thickness of snow cover not exceeding 10cm was registered in the studied areas in February 2012. Figure 6 shows the results of studying the dynamics of tritium concentration in the snow cover in 3 research areas in the vicinity of the Uzynbulak stream. An increase in the tritium concentrations in the lower layers of the snow cover (near-the-ground and intermediate layers) was observed in the riverbed and at a distance of 50 m from the Uzynbulak stream bed. In the near-the-ground layer the tritium concentration reached the values of 18,000 Bq/kg, in the intermediate layer it went up to 500 Bq.kg. In the same areas the tritium concentration in the surface snow layer was 30-90 Bq/kg. In the area located at a distance of 300 m from the stream bed the tritium concentration in all layers of the snow cover did not exceed 30 Bq/kg.

2.2.2. Baytles stream

The examined area located directly in the Baytles stream bed was occasionally flooded with water and covered with ice; therefore, the snow cover was not thicker than 3 cm and characterized tritium accumulation only in the period of the last snow precipitation. Figure 7 presents the results of measurements of tritium concentrations in the snow cover layers in three examined areas near the Baytles stream. The results (Figure 6, a) also show an increase in the tritium concentration with time both in the near-the-ground (1-3cm) and surface layers (0-1 cm). In this area the predominant mechanism is tritium emanation from the underlying surface.At a distance of 50m from the stream bed the tritium concentration was 30-80 Bq/kg throughout the thickness of the snow cover, and only in March in the surface layer of snow the tritium concentration could reach 190 Bq/kg. This result can be explained by the action of two mechanisms of tritium inflow into the snow cover: emanation from the underlying surface and fallout from the atmosphere.

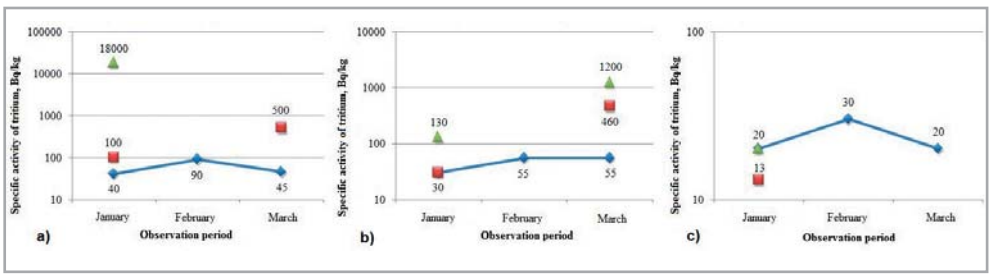

Figure 7. Dynamics of tritium concentration in the snow cover on the Uzynbulak stream:
a) in the stream bed, b) at a distance of 50 m from the stream bed,
c) at a distance of 300 m from the stream bed.

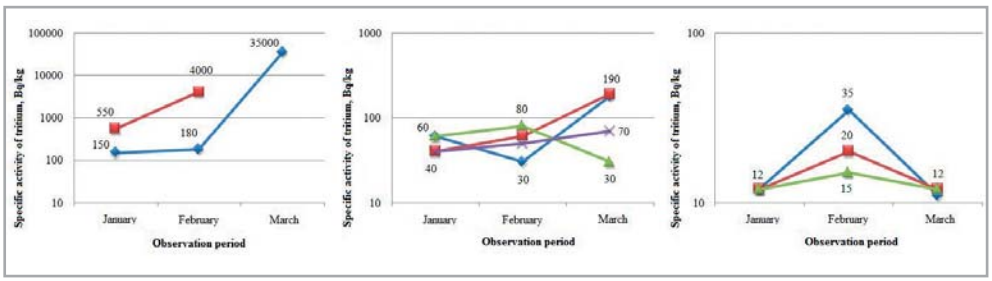

Figure 8. Dynamics of tritium concentration in the snow cover on the Baytles stream:
a) in the stream bed, b) at a distance of 50 m from the stream bed,
c) at a distance of 800 m from the stream bed.

The observed dependence can be explained by the fact that in the studied area, located directly in the beds of Uzynbulak and Baytles streams, the main mechanism of tritium inflow is tritium emanation from the underlying surface of ice or soil cover. At a distance of 50 m from the center of the stream bed there are two mechanisms of tritium inflow in the snow cover – tritium emanation from the underlying surface and condensation of tritium-contain-

ing water vapor on snow particles during snowfalls. At a distance of about 300 meters from the center of the stream bed the concentration of tritium in the snow cover did not exceed the background level of 12-35 Bq/kg.

3. DISCUSSION OF THE RESULTS

This research enabled us to obtain a clear picture of the tritium concentration near streams on the "Degelen" site and to get an indirect assessment of tritium contamination of the atmosphere. Figure 9 shows the spatial tritium distribution in the snow cover as a function of distance from all studied streams on the "Degelen" site in the 2011-2012 winter period. For each case (stream) the tritium concentration was normalized to the maximal value. The approximation curve in the figure shows the general character of tritium contamination depending on the distance from the stream beds.

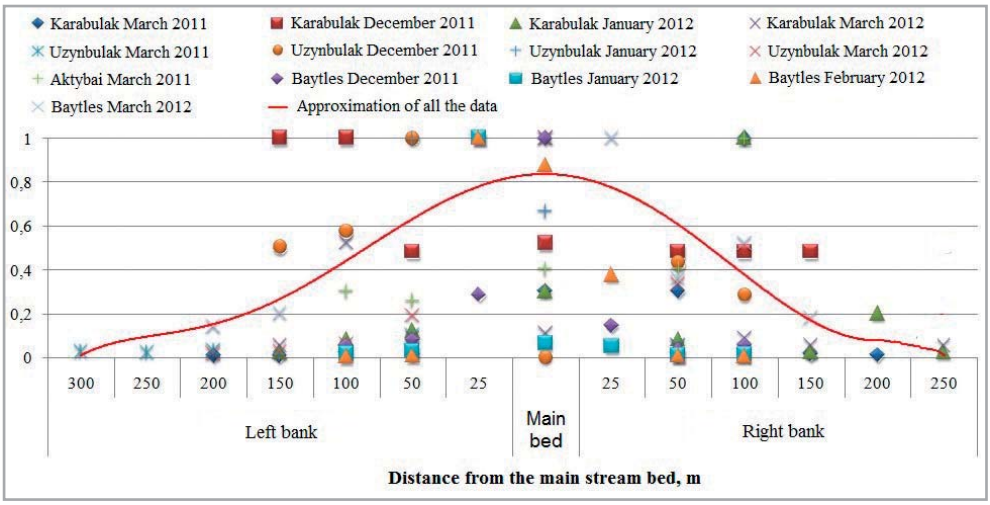

Figure 9. Spatial tritium distribution in the snow cover as a function of the distance from the stream beds of the studied streams normalized to the maximal value of tritium concentration

Studying of the spatial tritium distribution in the snow cover on the "Degelen" site showed that in the water ways maximal tritium concentrations in the snow layers were registered in the center of the stream bed, close to the water flow of the stream and ice cover. In the winter period the area of tritium contamination of the snow cover did not exceed 20 m from the stream bed. Due to intensive snow melting during spring floods, the main stream bed is overfilled with tritium-contaminated water, as a result some areas of the water way are subjected to tritium contamination, in such cases the snow cover has significant tritium concentrations at a distance of 300 m from the center of the stream bed.

The ratio of the tritium concentration in the near-the-ground layer to the tritium concentration in the surface layer clearly shows the influence of mechanisms of tritium penetration to the snow cover. For the values of the ratio equal to 1 and more, the main mechanism of tritium penetration is emanation from the underlying surface, and when the ratio is less than

1, tritium inflows into snow from the atmosphere [3]. Figure 10 shows the average ratios of the tritium concentration in the near-the-ground layer ($C_{near\text{-}the\text{-}ground}$) to the tritium concentration in the surface layer ($C_{surface}$) calculated separately for different STS areas. In the streams on the "Degelen" site (Figure 10) tritium concentration in the near-the-ground layer of the snow cover is always higher than in the surface snow layer. The ratio of $C_{near\text{-}the\text{-}ground}/C_{surface}$ in the snow cover varies from 6 to 14. This result makes it possible to suppose that the main mechanism of tritium penetration is emanation from the underlying surface of the soil or ice cover.

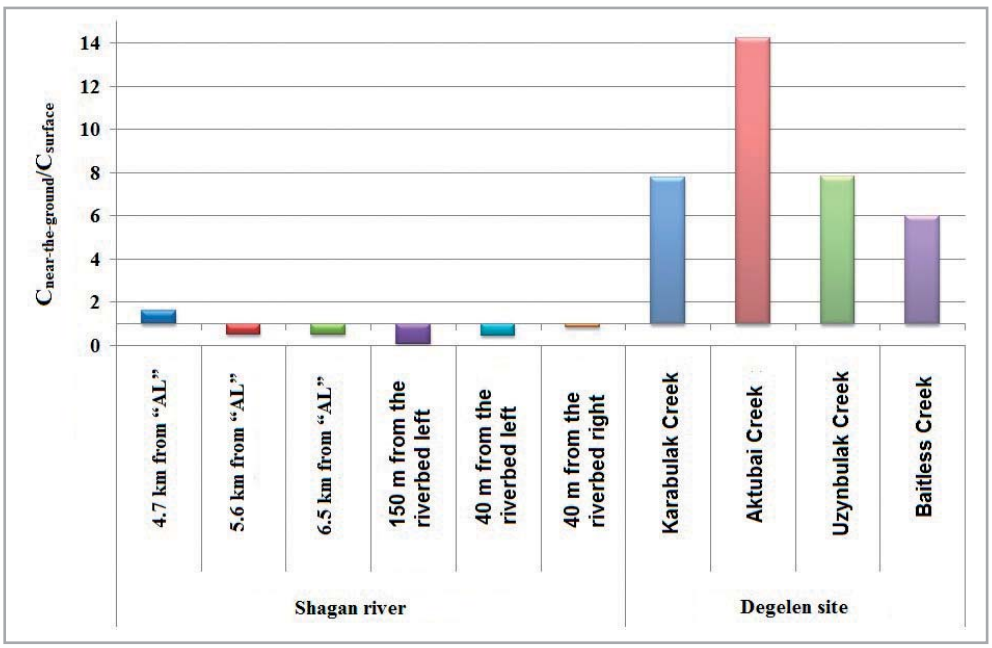

Figure 10. Average ratios of the tritium concentration in the near-the-ground layer to the tritium concentration in the surface layer of the snow cover

The dynamics of tritium concentration in the snow cover was studied in order to get a more precise information about the mechanisms of tritium penetration in the snow at different distances from the center of the Uzynbulak and Baytles streams. It was found out that in the beds of the Uzynbulak and Baytles streams the main mechanism was tritium emanation from the underlying soil or ice surface. At a distance of about 50 m from the center of the stream bed there are two mechanisms of tritium penetration in the snow cover – tritium emanation from the underlying surface and condensation of tritium-containing water vapor on snow particles during snowfalls. At a distance of about 300 m or 800 m from the center of the stream bed the concentration of tritium in the snow cover did not exceed the background level of 12-35 Bq/kg. This means that the stream does not affect this area, and at a distance of over 500 m from the streambed, the concentration of tritium is as low as the detection limit.

CONCLUSIONS

The results of investigations obtained in this work enabled us to more precisely determine the spatial tritium distribution by area in all streams at the "Degelen" site. Maximal tritium concentrations in the snow cover (tens of Bq/kg) were registered in the centers of the streams and are located in the areas having ice in the underlying surface. At a distance of not more than 100 m from the center of the stream bed the concentration of tritium in the snow cover decreased to the background level of 12-60 Bq/kg.

The assumption of the existence of two mechanisms of tritium penetration in the snow has been confirmed, moreover, the areas with both mechanisms of tritium penetration – emanation from the underlying surface and fallout from the atmosphere – have been identified. In the beds of the streams on "Delegen" site the prevailing mechanism is tritium emanation from the underlying soil or ice surface. At a distance of about 50 m from the center of the stream bed there are two mechanisms of tritium penetration in the snow cover – tritium emanation from the underlying surface and condensation of tritium-containing water vapor on snow particles during snowfalls. At a distance of more than 300 m from the center of the stream bed the concentration of tritium in the snow cover did not exceed the background level of 12-35 Bq/kg, which proves the absence of tritium contamination in this area.

The authors are grateful to the specialists of the Institute of Radiation Safety and Ecology V.A. Ulyankin and A.Zh. Esimbekov for their help in providing support and carrying out of field works, and O.N. Lyakhova and the group of general chemistry at the Department of the monitoring systems development for environment for preparation of snow samples.

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«ДЕГЕЛЕҢ» АЛАҢЫНЫҢ ҚАР ЖАМЫЛҒЫСЫНДАҒЫ ТРИТИЙДІҢ ҚҰРАМЫН ЗЕРТТЕУ

Турченко Д.В., Лукашенко С.Н., Айдарханов А.О., Ляхова О.Н.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Бұл мақалада, «Дегелең» алаңының Қарабұлақ, Ұзынбұлақ және Байтілес ағын суларының қар жамылғысындағы тритийдің құрамын зерттеу нәтижелері келтірілген. Қар жамылғысындағы тритийдің максималды шоғырлануы наурыз айында байқалды, олар арнаның орталығында орналасқан және беткі төсем қабатындағы мұз жамылғысы аймағының орын алуымен байланысты. Қыс мезгілі бойында қар жамылғысындағы тритийдің шоғырлануын өлшеу қарқыны зерттелді. Ұзынбұлақ және Байтілес бұлақтары арналарынан түрлі арақашықтықтағы қар жамылғысына тритийдің түсу механизмі жіті зерттелді.

Кілт сөздер: жерасты сулары, тритий, қар жамылғысы, Ұзынбұлақ, Қарабұлақ, Байтілес, ССП, радионуклидтердің жылыстауы, мұз жамылғысы, қар жамылғысының беткі қабаты, қар жамылғысының жербеткі қабаты, топырақтан тритийдің эманациялауы.

ИЗУЧЕНИЕ СОДЕРЖАНИЯ ТРИТИЯ В СНЕЖНОМ ПОКРОВЕ НА РЕКЕ ШАГАН

Турченко Д.В., Лукашенко С.Н., Айдарханов А.О., Ляхова О.Н.

Институт радиационной безопасности и экологии НЯЦ РК

В работе представлены результаты исследования содержания трития в снежном покрове на реке Шаган. Изучено пространственное распределение трития в снежном покрове относительно русла реки Шаган. Выявлена закономерность, что максимальные концентрации трития располагаются в центре русла и достигают 15 000 Бк/кг. За пределами русла водотока содержание трития составляет от 20 до 150 Бк/кг. Определены механизмы поступления трития в снежный покров, наиболее значимым механизмом поступления трития за пределами русла является конденсация тритийсодержащих водяных паров на частицах снега в момент выпадения атмосферных осадков.

Ключевые слова: русловая вода, грунтовая вода, тритий, снежный покров, река Шаган, СИП, миграция радионуклидов, ледяной покров, поверхностный слой снежного покрова, приземный слой снежного покрова, эманация трития из почвы.

УДК 577.4:621.039.54:614.876

STUDIES OF RADIOECOLOGICAL CONDITIONS AT THE SPENT FUEL STORAGE OF THE IGR REACTOR

Gaydaychuk V. A., Deryavko I.I., Meshin M. M., Chernyadev V.V.

Institute of Atomic Energy NNC RK, Kurchatov, Kazakhstan

General information about the research reactor IGR spent-fuel storage, quantity and the arrangement of its storage cells is provided in the paper. The paper also introduces the research outcomes on radioecological conditions at the spent-fuel storage and adjoining territory (research performed in 2012), which have shown no release of noticeable amounts of radioactive products outside the spent-fuel storage and absence of overdosage to the personnel of the reactor complex IGR working in vicinity of the spent-fuel storage.

INTRODUCTION

In order to obtain reliable information about the current Radioecology at former Semipalatinsk Nuclear Test Site it is required, above all, to perform systematic and comprehensive environmental studies at such radiation hazardous testing facilities as "Balapan", "Experimental Field" (Opytnoye Pole) site and "Degelen" as well as the newly discovered facility "Burial", located dangerously close to the town of Kurchatov. At the same time, information on the STS territory conditions would be incomplete without knowing the radioecological situation at two complexes of research reactor of the Institute of Atomic Energy NNC RK – research reactor complex "Baikal –1" and research reactor complex IGR – located within the STS (Figure 1).

The latter is because of these reactor systems include many radiation hazardous facilities: first, the nuclear reactors themselves – the operating water-cooled heterogeneous research reactor IVG.1M, operating pulse graphite reactor IGR and non-operating ampoule reactor RA, and second, fifty seven storages for different purposes – temporary, interim and permanent storages for sources of ionizing radiation [1, 2], radioactive waste storage, storage of nuclear materials, storages of reactor's fresh fuel, spent fuel storage facilities.

The radiological situation at the radiation hazardous facilities "Baikal –1" and IGR is monitored by the relevant divisions of the IAE NNC RK, which is to ensure acceptable radioecological conditions at these facilities and on their surrounding areas. In this regard, this paper puts forward the findings of the radioecological studies at one of these facilities of the Institute – spent fuel storage for IGR reactor, which has stored for about 43 years IGR's uranium-graphite fuel elements of the core damaged in one of the out-of-limit tests.

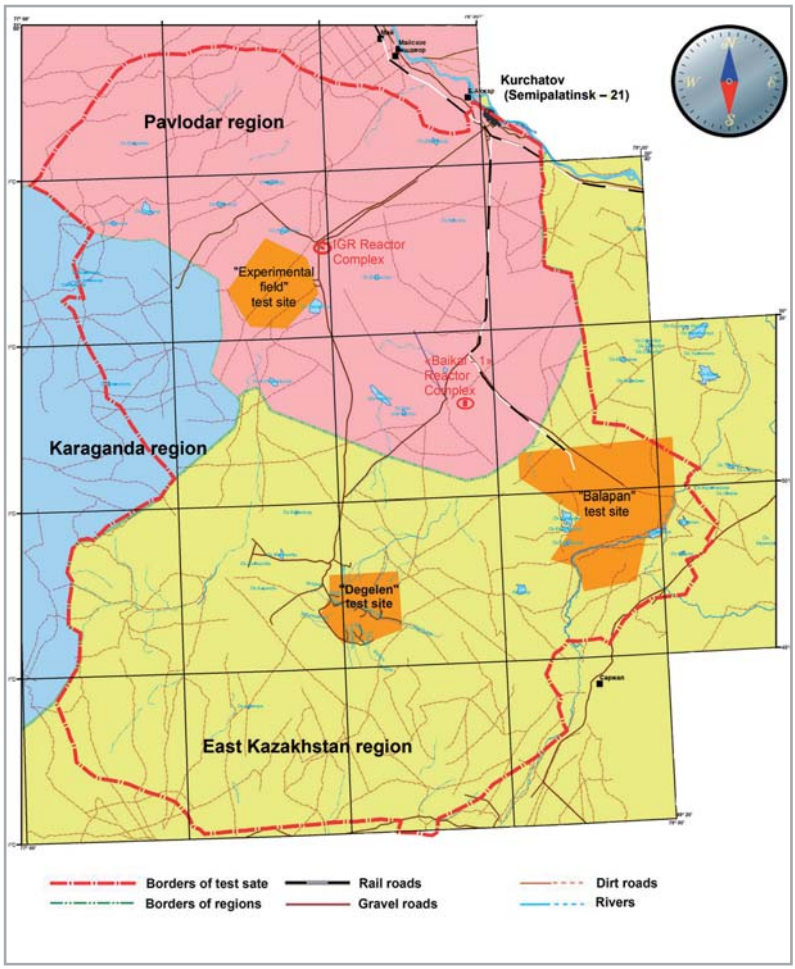


Figure 1. Schematic map of the reactor facilities location and major testing grounds at the Semipalatinsk Test Site

1. BACKGROUND INFORMATION ABOUT THE IGR REACTOR SPENT FUEL STORAGE

The storage is located at the IGR reactor complex in gable facade room of the earth-mounded process building with a single-ended ceiling (Figure 2). The opening in front of the storage entrance is both an opening in front of the emergency exit of the process building.

There are two cells in the storage for storing nuclear fuel: cell No. 1 is the fuel bell of the storage, and cell No. 2 – 1.5 m deep pit, covered with protective concrete slab. To access the upper transshipment metal hatch of the bell there is a staircase arranged with a handrail (Figure 3a), laid directly on the embankment of the building, since this hatch, sealed with the IAEA stamp, is located on the ceiling of the process building (Figure 3b).

a) b)

Figure 2. Entrance to the process building (a)
and exterior of the building (b) from the emergency exit side

a) b)

Figure 3. Stairs rise to the building's ceiling (a) and sealed top hatchway of the bell (b)

The fuel bell (in cell No. 1) stores in two layers eight sealed metal drum-containers with fragments of uranium-graphite fuel blocks. The design of these drum containers (Ø660×1350mm – 6 pieces, Ø420×1770 mm – 2 pcs) is a leak-tight (the container cover is tightly bolted to the container through the rubber gasket).

To access the storage pit (to cell №2) one should enter the pocess building through the front door and opening (Figure 2 a) and walk down the main corridor (Figure 4 a) into the building gable facade to the opening in front of the storage and an emergency exit, open the front door of the storage (Figure 4 b) and go into the room of the storage (Figure 4 c).

The last image of this figure shows that the storage pit is closed with four sections of the protective concrete slab (in demountable slab each section is an extension of the nearby one, and with inclined planes of contact). The protective slab is under the IAEA seal (control wire is threaded through four eye bolts screwed into the protective slab outer section). This image also shows the reactor fuel storage cell numbers (№ 2 and № 1): on one section of the protective slab of the pit is labelled with "2", and the IAEA sealed green metal cover on the opening of the fuel bell is labelled with red "1" (as seen in Figure 3 b, the digit "1" is labelled on the top shifting hatch of the bell). Immediately after opening of the bell is a 100 mm thick lead protective wall, assembled from 50 mm thick lead-block "bricks", behind which metal drum-containers with parts of the reactor fuel are stored.

a) b) c)

Figure 4. The building process corridor (a), front door to the storage (b), interior of the storage (c)

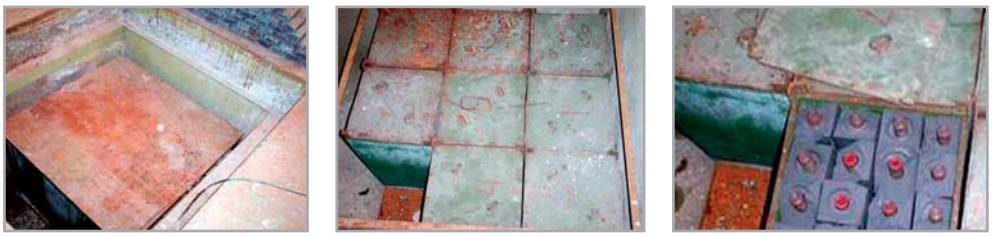
For opening the pit there is a 1 ton lifting capacity mechanical beam crane which removes the required number of sections of the protective concrete slab from the pit. The pit stores eight leak-tight sealed metal containers (size of each – 410×410×760 mm) with uranium-graphite fuel blocks. The fuel blocks are stored in containers in the following manner. Five blocks (dimensions of each one – 98×98×130 mm) installed on each other, form a low column. In the channel formed on the axis of each column a leak-tight metal case with absorber is inserted in the form of boron carbide powder. Sixteen of these columns are placed in a metal container, i.e. each container holds up to eighty-uranium-graphite blocks. All eight fuel containers are placed in a metal frame with a metal tiltable lid, on which lead- blocks "bricks" are stacked, forming an additional 50 mm thick protective lead layer.

By removing all the lead blocks from the frame lid (in Figure 5a these remote blocks are stacked on top of each other on the edge of the pit) one can access to the containers with fuel blocks (for which it is enough to fold back the frame lid). These eight semi-hermetic containers, shown in Figure 5b, store spent uranium-graphite blocks containing a total of 1,085 kg of highly enriched uranium impregnated graphite [3, 4]. (Given the fragments of fuel blocks in eight drum-containers in the fuel bell the total amount of reactor fuel in the storage is 2604 kg).

One should bear in mind that the fuel blocks of any container in the pit can only be accessed after removing the container's lid that is through a rubber gasket is joined firmly to the container by sixteen bolts. When examining the parts and materials of the storage in 2001 [4] a lid of one of the containers was opened. The picture taken during the examination (Figure 5c) clearly shows sixteen columns of the fuel blocks with embedded in them devices for ensuring nuclear safety in long-term storage of fuel.

It remains to note that in the surveyed storage the IAEA sealed only protective concrete slab of the pit with the fuel, the metal lid on the fuel bell opening and top transfer hatchway of the bell. All others are sealed by the relevant divisions of the Institute of Atomic Energy NNC RK. At the same time the IAEA inspectors once in a quarter monitor the secu-

rity of the three of its seals and once a year instrumentally remotely check for the presence of irradiated fuel in the pit and in the fuel bell.



a) b) c)

Figure 5. The frame with the containers in the pit (a), eight containers with fuel blocks (b), fuel blocks in one of the uncovered containers (c)

2. RADIATION SITUATION IN THE STORAGE AND ON ADJACENT TERRITORIES

The 2012 survey found (Figure 6) quite satisfactory Radioecology conditions at the storage and in its surrounding areas. The β-particles flux density measurements performed outside the building process, in front of the building entrance, in the entrance opening, in the building corridors and in all its facilities up to the opening before the door of the storage found no significant radioactive products transport outside the storage: the fluxes at different measured points ranged from 0 to 16 part./(cm^2*min) with pronounced tendency to decrease in the direction from the storage. Thus in the storage room the β-particles flux densities were significantly higher and ranged from 50 to 105 part./(cm^2*min).

Such a low contamination of the storage and absentation of significant radioactive products migration beyond it is quiet understandable. First, the design of the containers with fuel, and in the pit, and the fuel bell is semi-hermetic, which virtually eliminates the radioactivity carryover from these closed and sealed containers. Second, the cases of opening the containers, that is, those states of the storage, when the radioactivity carryover probability is highest, have been extremely rare in the practice of the storage. Thus, the drum-containers in the fuel bell have never been opened for all 43 years of operation, and out of the eight containers in the storage pit only two containers were opened: containers M-204 opened four times (Figures 5 b and 5 c show red digit "4" on its lid), and container M- 206 opened once (Figure 5 b, the container is labelled with "6" on its lid). It is appropriate to note that during the annual instrumental check for irradiated fuel in the pit and in the fule bell the IAEA inspectors do not open the containers.

Also the survey found no danger of overexposure of the IGR reactor complex staff operating in the process building rooms. The dosimetric measurements showed that the exposure dose rates at different points both the outside of the building, and inside it and all the way up to the opening in front of the storage, did not exceed 0.2 μSv/h. Directly at the storage door EDR was 0.5 μSv/h, and in the doorway – 0.8 μSv/h. Inside the storage at all measured points the EDR is markedly higher than μSv/h, and its maximum, 10.4 μSv/h, was on the

surface of the protective concrete slab over the pit with the fuel (it is interesting to note that when the pit is uncovered the EDR on the surface of the protective lead layer on the container exceeded this value by three orders of magnitude and was about 10 μSv/h).

Figure 6. Examination of the storage radiation

In the surveyed storage, except for fuel storage pit, there is an additional 0.8 m deep pit, designed for storing radioactive wastes, in which two sealed semi-leak-tightmetal containers with IGR reactor spent radioactive filters are stored. The pit is covered with a protective concrete slab (an additional protective lead layer between the containers and the concrete slab is absent). This three-section concrete slab can be seen in the middle picture in Figure 6, where the central section of the slab is labelled with "3", indicating the number of the additional storage cell. Measuring the γ-radiation doses near the auxiliary storage pit found that the maximal EDR is on the surface of the slab central section and is 6.2 μSv/h.

CONCLUSION

The paper described the IGR reactor's spent fuel storage and storing conditions in it of highly enriched nuclear material, gave the findings of the radiological examinations of the storage conditions and surrounding area. It was found that the storage has quite satisfactory Radioecology (no significant migration of radioactive products beyond the storage and there is no danger of overexposure of the IGR reactor staff operating in the rooms next to the storage). The obtained positive results from the storage examination have fully confirmed the fact that the fuel storage and its maintenance conditions, and radiation monitoring in storage and the surrounding area, implemented by the relevant departments of the Institute of Atomic Energy, really guarantees an acceptable Radioecology of this radiation hazardous facility.

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ИГР РЕАКТОРЫНЫҢ ПАЙДАЛАНЫЛҒАН ОТЫН ҚОЙМАСЫНЫҢ РАДИОЭКОЛОГИЯЛЫҚ ЖАҒДАЙЫН ЗЕРТТЕУ

Гайдайчук В.А., Дерявко И.И., Мешин М.М., Чернядьев В.В.

ҚР ҰЯО Атом энергиясы институты, Курчатов, Қазақстан

ИГР зерттеу реакторының пайдаланылған отын қоймасы, саны және оның сақтау ұяшықтарының қондырғысы туралы жалпы мәліметтер ұсынылды. 2012 жылы орындалған қойманың және оған шектеулі аумақтың радиоэкологиялық жағдайын зерттеу нәтижелері келтірілді, қойма шегінен радиоактивті өнімдерді айқын алып шығуының жоқтығы және қоймамен шектес жайларда жұмыс істейтін ИГР реакторлық кешен персоналының аса сәулелену қауіптілігінің жоқтығын көрсетті.

ИССЛЕДОВАНИЕ РАДИОЭКОЛОГИЧЕСКОГО СОСТОЯНИЯ ХРАНИЛИЩА ОТРАБОТАВШЕГО ТОПЛИВА РЕАКТОРА ИГР

Гайдайчук В.А., Дерявко И.И., Мешин М.М., Чернядьев В.В.

Институт атомной энергии НЯЦ РК, Курчатов, Казахстан

Представлены общие сведения о хранилище отработавшего топлива исследовательского реактора ИГР, количестве и устройстве его ячеек хранения. Приведены результаты выполненных в 2012 году исследований радиоэкологического состояния хранилища и прилегающей к нему территории, которые показали осутствие заметного выноса радиоактивных продуктов за пределы хранилища и отсутствие опасности переоблучения персонала реакторного комплекса ИГР, работающего в смежных с хранилищем помещениях.

PART: RADIOECOLOGICAL CONDITIONS AT OTHER NUCLEAR TEST SITES IN KAZAKHSTAN

УДК 614.876:577.4:539.26

REMEDIATION OF NUCLEAR TEST EFFECTS ON THE USTYURT PLATEAU

Poleshko A.N., Glushchenko V.N., Lukashenko S.N., Severinenko M.A., Nikolaev I.M., Levashov M.A., Glushchenko G.M., Milts O.S., Reznikova R.A.

Institute of Nuclear Physics NNC RK, Almaty, Kazakhstan

The paper reports on the outcomes of comprehensive nature conservation activities on peaceful nuclear explosion sites at Ustyurt Plateau in Aktoty, Mulkaman, Kindikty: assessment of contamination, design and implementation of remediation works. The nuclear explosions parameters have been described. Technologies and methods of remediation are considered. The post-remediation monitoring has shown that modern radiation environment comply with the established sanitary standards. A conclusion has been made about effectiveness of the methods and technologies to reduce the radiation risks.

INTRODUCTION

The need for remediation of the underground nuclear test areas on Ustyurt plateau (Mangistau Oblast) is stipulated by the following reasons:

- underground nuclear explosions (UNE) are on the pastoral farming sites in the area of "summer pasture" and wells for the livestock;
- self-regeneration processes on the large area of technologically modified site have been moving slowly which disrupts the ecological balance of the area;
- wind erosion of the contaminated spot entails contamination of vegetation;
- according to the recommendations of the International Commission on Radiological Protection, the presence of a potentially dangerous object in the inhabited area is the constant stress factor for the population.

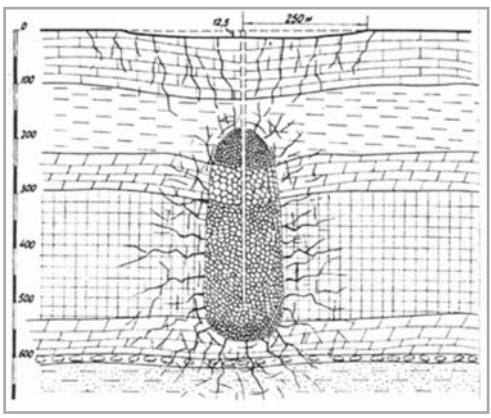
The area, where three underground nuclear explosions were conducted for peaceful purposes in the 70s of the last century, is 290 km away from Aktau city and located on Ustyurt plateau 110 km south-east of Sai-Utes township, 105 km away from Ustyurt station in Mangistau Oblast.

The purpose of UNE conduction on Ustyurt plateau was to create water reservoirs in sinkholes and to study engineering seismology. Such craters on the surface can be formed by the collapse of explosion cavity and all geological rocks that are lying above this plane; therefore the most of the cavity appears on the surface in the form of a cone-shaped collapse. This happens when the rock lying above the cavity does not possess the "swelling" property when collapsing into the cavity. The diameter and depth of such craters allow using them for creation of reservoirs in the arid areas.

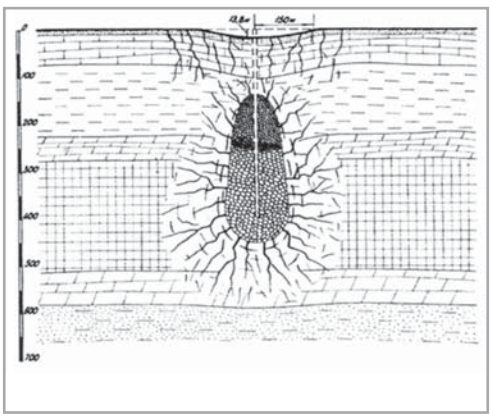
It was assumed that sinkholes formed by the collapsed cavity would be filled with water from the first aquifer in the emplacement hole area. But it did not happen; the bottom

of craters got filled with melt waters for a short time and then dried out turning into dry-type playa.

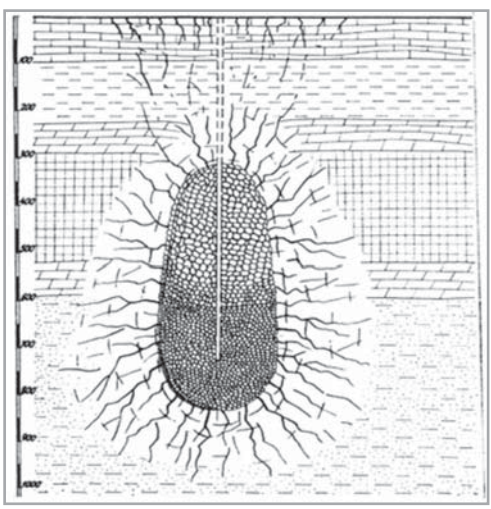
Mechanical effect of the explosion on the massif could have established hydraulic connection between the aquifer of Cenomanian complex (600 m) and collapsed cavity with the further radionuclide contamination of these waters. The assessments have shown that the radius of radionuclide distribution in the underground Cenomanian aquifers can be up to 400 m away from the centre of the explosion and up to 110 m subject to sorption of clays.



a) hole T-6



b) hole T-2



c) hole T-1

Figure 1. Underground Nuclear Explosion Pattern

It should be noted that the depth of craters formed in the study area is significantly less than of those formed under the circumstances of similar activities on Nevada test site in the U.S. This may be the result of differences in geological environment physical properties between the centre and the surface of the explosion. The fact of no crater being formed during the explosion in T1 hole can be explained by too deep location of nuclear charge during the UNE conduction.

Table 1 and Figure1 show the characteristics of UNE conducted in mass glauconite quartz sand with clay (T1) and in chalk rock (T2, T6).

Table 1.

Characteristics of underground nuclear explosions on Ustyurt plateau

Explosion parameters	T-2 Hole	T-6 Hole	T-1 Hole
Time of explosion	**06.12. 1969**	**12.12. 1970**	**23.12. 1970**
Explosion yield, kg	30	80	75
Depth of explosion, m	407	497	640
Cavity radius, m	65	100	100
Crushing zone, m	170	225	240
Fractured zone, m	275	350	410
Height of pillar caving, m	270	340	400
Crater diameter, m	300	500	0
Crater depth, m	13.8	12.8	0

Assessment of radioactive contamination at UNE sites

Radiation environment at the sites

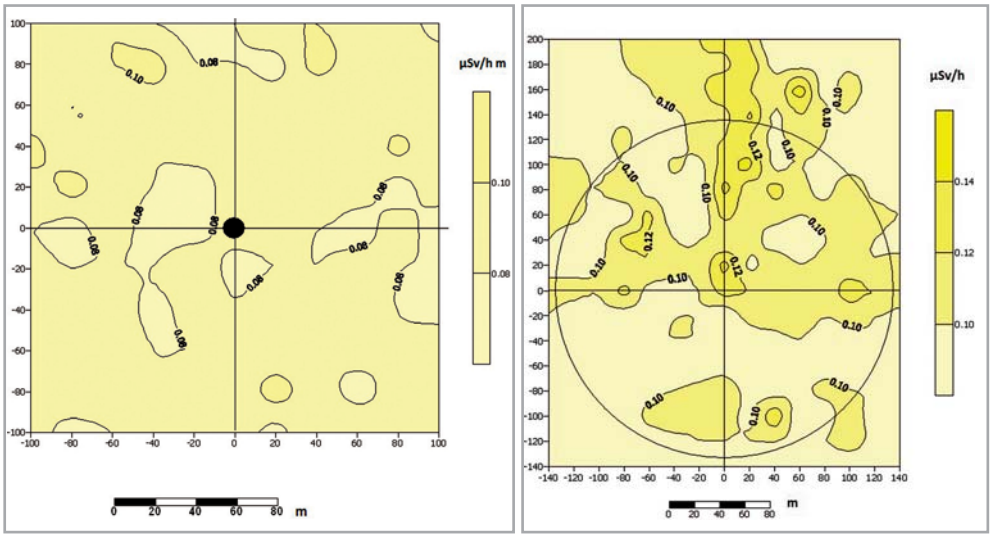
The main feature of three nuclear explosions was the fact that they had no radioactivity leak and radiation did not exceed the background levels.

The results of numerous surveys of the areas where industrial underground nuclear explosions were conducted prove that the use of nuclear explosive technologies for national economic purposes did not become the cause of serious radioecological problems.To assess the radionuclide contamination, in 2004 the Institute of Radiation Safety and Ecology conducted reconnaissance studies during which three water samples, 73 soil samples, and 10 vegetation samples were taken, 334 measurements of radiation parameters were taken in 85 survey points, 3 measurements of radon activity were taken in living premises. Two spots with radioactive contamination were found.

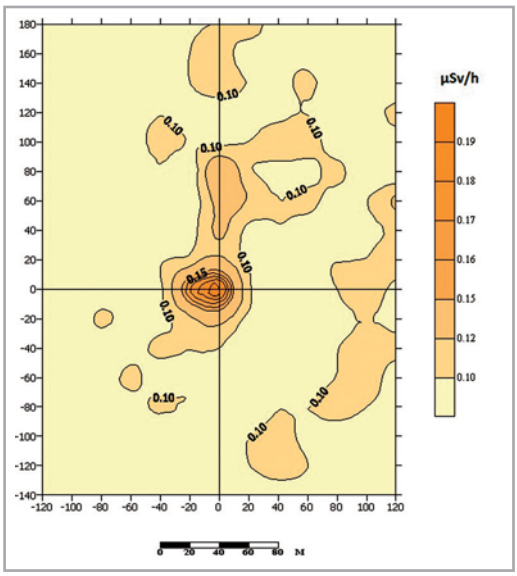
In 2005, in order to study the nature of radioactive contamination of the area, the Institute of Nuclear Physics performed additional field works to study the distribution of radionuclides in various environmental compartments, and to define the boundaries of reclaimed areas. The UNE areas were surveyed by means of gamma survey on foot on a 20×20 m grid with layer-by-layer sampling along the radial profiles.The cartogram (Figure 2) implies that the gamma field intensity on the site areas within the sinkholes varies from 0.10 to 0.14 μSv/h. These values correspond to the normal gamma background for this region.

Soil samples (total of 232 samples) collected at Ustyurt plateau within the sinkholes were analysed by means of gamma-spectrometric analysis to determine the concentrations of Cesium-137, Americium-241, Lead-210, Radium-226, Lead-214, Thorium-234, Thorium-232, Potassium-40 isotopes. Concentration of natural radionuclides in all selected samples does not exceed concentrations that are typical to such soils. Concentration of artificial radio-

nuclides (^{137}Cs and ^{241}Am) in all selected samples does not exceed the background concentrations caused by global atmospheric radioactive fallouts. The exceptions are two local areas on T1 and T6 sites. No excess EDR was noted on T-2 site.



a) UNE T-1 b) UNE T-2



c) UNE T-6

Figure 2. Gamma-filed cartogram

Detailed description of radioactively contaminated spots (RCS)

Ustyurt plateau had two areas referred to radioactively contaminated sites: RCS-1 and RCS-2.

RCS –1. Contamination on T-1 site is located at the observation holes and appears in the form of a spot of irregular shape of about 30 m in diameter on the surface. According to the field gamma-spectrometry, the sandy-clay ground is contaminated with ^{137}Cs isotope. EDR on the ground surface does not exceed 0.33 μSv/h. Contamination penetrates to the depth of 20-30 cm. The area with excess gamma-activity of up to 0.33 μSv/h is noted at about 150 meters away from the emplacement hole on T-1 site (Figure 3a) near the observation holes. Radioactive contamination represents a spot of irregular shape on the ground surface elongated in sub-northern direction for up to 25 m. According to the field gamma-spectrometry, the sandy-clay ground is contaminated with ^{137}Cs isotope.

In stratified soil sample collected from the depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm in the centre of anomaly, the specific activity of ^{137}Cs is 5,707 Bq/kg, 1771.9 Bq/kg, 718.1 Bq/kg and 550.9 Bq/kg accordingly. Contaminated grounds are not radioactive wastes and shall be referred to the materials of limited use. It should be noted that concentration of ^{137}Cs decreases closer to the anomaly periphery and with the depth of sampling.

RCS-2. The emplacement hole on T-6 site (Figure 3b) is the radiation hazardous sites. Fencing around the wellhead area (previously it was a fence made of metal pipes of 40 mm in diameter) was destroyed and the pipes were partially removed.

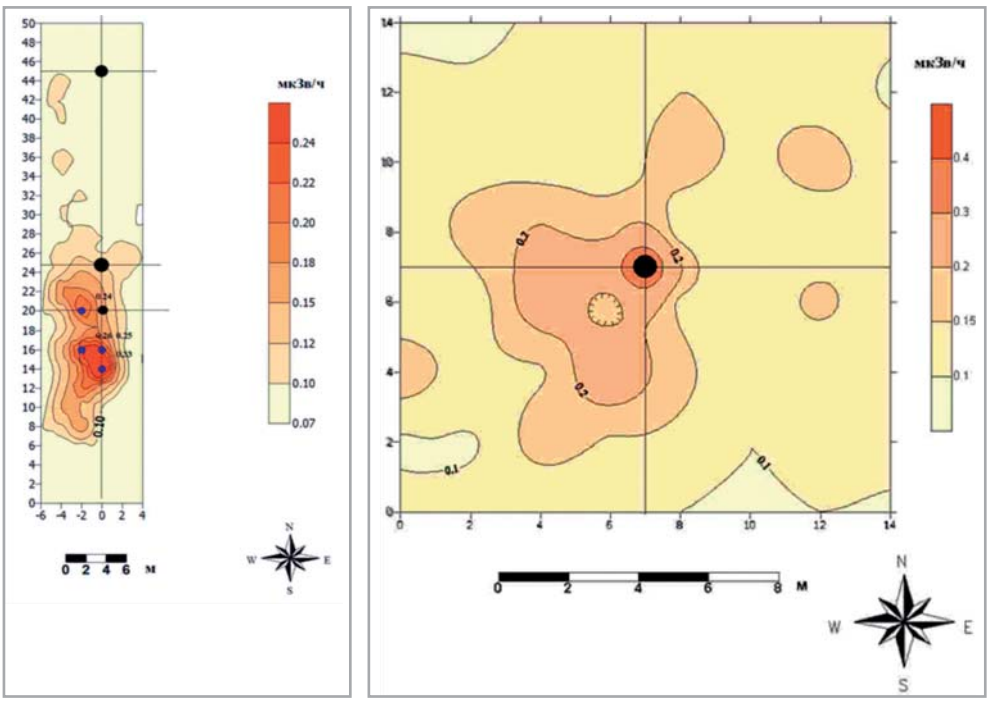
Radiation background in the site area does not exceed 0.1 μSv/h. EDR at 1 m away from the casing pipe from the southern side is 0.62 μSv/h and from the northern side – 0.22 μSv/h. The direction of positive gradient of gamma-field goes upwardly along the hole starting from the height of 1 m from the surface. The maximum EDR of 15 μSv/h is inside the hole on the top at the concrete plug. According to the field gamma-spectrometry, ^{137}Cs is the main dose-forming radionuclide.

a) General view of UNE-1

b)- General view of UNE –2

Figure 3. Radioactively contaminated spots № ground contamination at the hole was found.

The gamma-field cartogram within the radioactively contaminated spots is shown on Figure 4.



a) UNE-1 b) UNE-2

Figure 4. Gamma-field cartogram

Activities to eliminate radiation risks

Design of remediation works

In accordance with the legislation of the Republic of Kazakhstan, the environmental actions are being taken on the basis of the approved design documentation. In this connection, the remediation plan for contaminated areas on T1 and T6 sites was developed by INP of the NNC.The efforts to restore the radioactively contaminated areas include conservation of the wellhead of T6 hole and decontamination of contaminated daylight area of T1 hole.

Two options of contaminated soil disposal were considered during the plan development. Option 1 provides for the waste disposal in the wellhead area of T-1 emplacement hole. RCS-1 will be liquidated by excavation of contaminated soil and backfilling the reclaimed area with radiation-free soil. Contaminated soil will be disposed by way of trench burial in the wellhead area of T-1 emplacement hole.

The trench for disposal of limited use materials will be dug within the limits of the wellhead area of T-1 emplacement hole at 30 m away from the emplacement hole. General enclosure of the disposal site and emplacement hole is envisaged in the form of the ditch of 1.5m deep and 1.4 m wide.Option 2 provides for the removal of contaminated soil, packing

thereof in bags and further transportation by specially prepared motor vehicles to be disposed in depleted pit 2-3 in Aktau.

The cleaned up site will be reclaimed by means of backfilling with radiation-free soil. For the purpose of waste disposal, the radioactive waste burial site will be constructed in the open pit in accordance with the adopted technical solutions with regard to the on-site disposal.The options in question are different in terms of waste disposal place. Since the second option is not economically advantageous because of additional transportation cost related to the haulage of wastes to the pit, as well as the potential risk of disturbance of shipping containers (bags) and related possibility of contamination distribution on the way of motor vehicles, option 1 was adopted to take technical solutions.

RCS-2 will be liquidated by means of conservation of the wellhead of T6 hole to localize fixed radioactive contamination on the hole plug through the construction of shielding around the hole from the reinforced concrete "Sarcophagus" with the wall thickness of 1 m. Upon implementation of this method of RCS-2 liquidation, the intensity of penetrating gamma radiation will not exceed 0.11 μSv/h on the surface of concrete shielding.Due to the lack of information about hole construction, any works connected with hole disintegration will be impractical. Therefore alternative options for hole conservation have not been considered. To prevent access of people and domestic animals to the area of T-1 and T –6 sites, the enclosure is supposed to be built in the form of a ditch of 1.5 m deep and 1.4 wide.

To determine the volume of contaminated soil to be disposed based on the results of gamma survey on foot and gamma- spectrometric analysis of soil samples taken from RCS-1, the layer-by-layer vertical sections of contamination site were developed (Figure 5). The absolute gamma activity of contaminated soil was calculated. When estimating the area of radioactive contamination distribution, the specific activity of main radioactive ^{137}Cs isotope in the range of 300 and 150 Bq/kg was considered as the boundary condition. The results are shown in Table 2.

Table 2.

Parameters of RCS-1 in the area of T-1 site

Boundary condition	Layer thickness	Contaminated area	Specific activity	Volume	Weight	Absolute activity of Cesium-137 isotope
Bq/kg	cm	**m^2**	**Bq/kg**	**m^3**	**kg**	**Bq**
>300	0-5	63.7	1000	3,2	5,120	5,100,000
	5-10	28.4	590	1.4	2,240	1,300,000
	10-20	9	410	0.9	1,440	590,000
	20-30	2.7	380	0.27	432	160,000
	0-30			5.8	9,240	7,150,000
>150	0-5	92.6	770	4.6	7,360	5,700,000
	5-10	63.2	380	3.2	5,120	1,900,000
	10-20	32.1	260	3.2	5,120	1,300,000
	20-30	18.4	230	1.8	2,880	660,000
	0-30			12.8	20,480	9,560,000

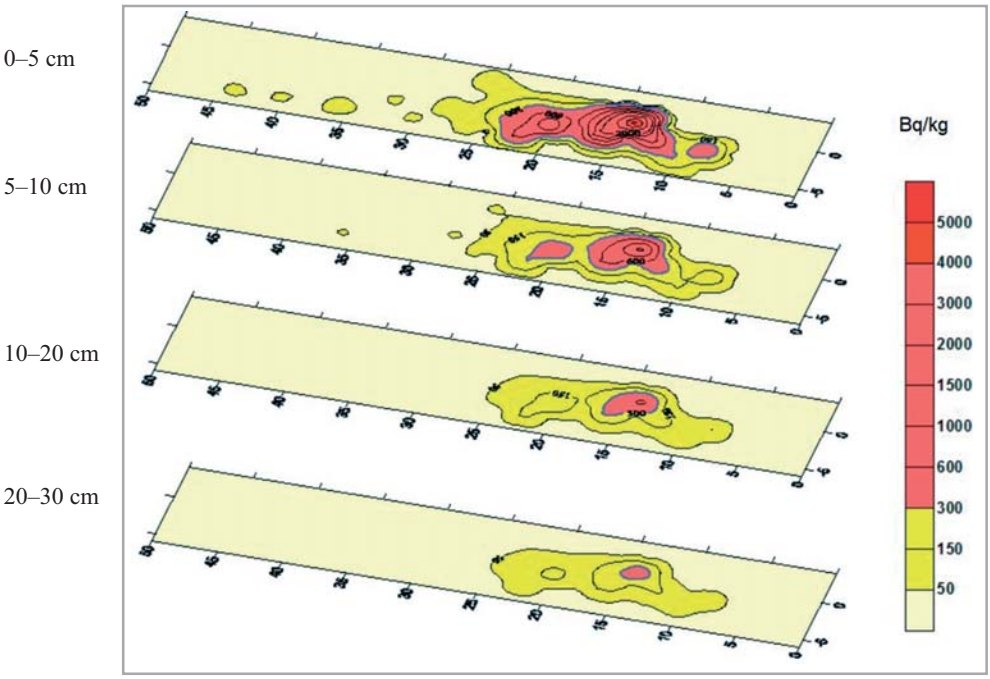


Figure 5. Vertical distribution of Cesium-137 isotope on RCS-1 (T-1)

Contaminated area on the day surface with ^{137}Cs specific activity more than 300 Bq/kg is 63.7 m^2, and the area with excess values more than 150 Bq/kg is 92.6 m^2. With the depth the contaminated area sharply decreases. The volume of contaminated soil on RCS-1 to be buried to ensure the required level of radiation safety is 13 m^3

Technical solutions for the construction of disposal site for limited use materials

Construction and operation of the disposal site for the materials of limited use (MLU) includes the following stages:

- soil excavation and bed construction for waste placement;— placing of materials of limited use;
- sheltering of materials of limited use;— enclosure of burial site;
- monitoring.The dimensions and design of the MLU disposal site were determined based on the total volume of the limited use materials of to be buried and safety of work performance.

Dimensions of the burial pit for MLU:
on the bottom – 2 × 3 m; on the top – 5 × 6; depth – 3.5 m

In the course of designing of the MLU disposal site the measures were envisaged to ensure that the site is waterproof against surface and ground waters, and to provide erosion control. The surface and sides of the ditch shall be covered with a layer of impermeable soil (clay) of at least 0.5 m thick and hydrogeochemical barrier on a hexacyanoferrate basis.

The surface of the MLU to be buried shall be covered with clay screen and then with stone-macadam pavement (each layer at least 0.5 m thick), concrete shielding and a layer of clean soil of about 1 m thick. The total thickness of cover shall be at least 2 m. The bottom of the ditch shall be first of all covered with the soil with the activity over 300 Bq/kg taken from the centre of RCS and then with the soil with the activity over 150 Bq/kg. The soil taken out but not utilised in the construction of the MLU disposal site shall be backfilled into the place where soil was removed for the burial purposes.

Localisation of fixed radioactive contamination at the concrete plug of T-6 hole (RCS-2) in the Mulkaman area

Under the design and estimate documentation (DED), the practical solution of this problem was assumed to be implemented by means of shielding construction around the hole with the use of reinforced concrete with the wall thickness of 1 m.Due to the changed economic situation (appreciation of building materials), the technical solution was changed. Justification for changes in the technical solution regarding RCS-2 liquidation was prepared. This justification was submitted to the Institute of Radiation Safety and Ecology (IRSE) of the NNC of the Republic of Kazakhstan to assess its viability. After the receipt of positive opinion from the IRSE, this solution was used in the works carried out on T6 site.

The reinforced concrete "shelter" (*sarcophagus*) on the wellhead ground of T-6 hole on RCS-2 was replaced with the rectangular shelter made of limestone with the dimensions 3 x 3 x 2.6 m and wall thickness 0.2 m with the interior being filled with the mixture of clay and gravel.Below is the comparative calculation of the shielding capacity of shelter under both options.

Upon expiry of more than 30 years, the main gamma emitter in the nuclear explosion products will be ^{137}Cs radionuclide with the gamma quantum energy of 0.66 MeV.

In the adopted solution the complete concrete shielding is replaced with the compacted mixture of clay and gravel. The difference in shielding capacity is that the cement is replaced with clay. The linear attenuation coefficients of clay and cement in terms of 1 MeV gamma quantum energy are 0.130 and 0.133 cm^{-1} respectively. The difference 2 %) is within the limits of calculation accuracy.

The use in the proposed solution of the limestone layer of 20 cm thick with the linear attenuation coefficient of 0,187 cm^{-1} as an outer load-carrying frame will slightly increase the shielding capacity of the shelter as compared to the concrete that has linear attenuation coefficient of 0.154 cm^{-1}.

The shielding capacity of shelter in the planned and amended options is calculated with a large safety factor. With the shielding thickness being 1 m, the attenuation multiplicity for 0.66 MeV gamma quantum energy is more than 100 times. With the initial total dose being 0.62 μSv/h subject to the background 0.12 mSv/ h and safety factor for calculations 2 as required by the Sanitary Requirements for Radiation Safety, the shielding multiplicity required in calculations shall be 10 in order to comply with standard KPR-96 (0.3 μSv/h), i.e. the actual safety factor adopted in the project is 20, so the change in shielding density even up to 1 g/cm^3 (water) provides the desired shielding capacity.

Remediation work methods

The contaminated area was preliminary marked by pegs according to gamma survey data. The top soil of 30 cm thick within the limits of the marked area was removed by bulldozer. The collected soil was hauled by tractor bogey to the burial trench at T1 hole in accordance with the safety regulations. The area of decontaminated site is covered with a layer of potentially fertile soil 30 cm thick. The EDR on the surface of decontaminated site is 0.07 – 0.11 μSv/h.

Disposal site for contaminated soil was constructed on T-1 site in the area of Akotty summer pasture in the immediate vicinity of the wellhead of the emplacement hole in accordance with the DED. The disposal site is a 5 x 6 x 3.4 m trench. The trench sides and bottom are concreted and have water proofing made of clay material with bitumen greasing. Contaminated soil is placed in a layer of at least 1m thick in the trench constructed near the surface. The volume of disposed contaminated soil is 12.8 m^3 with the specific activity of 466 Bq/kg. Contaminated soil is covered with a layer of clay and a layer of gravel. On the surface the trench is covered with a concrete slab 0.3 m thick and a layer of potentially fertile soil 1 m thick. EDR on the top of the disposal site for MLU is 0.12 μSv/h.In order to limit the access of people and domestic animals to the MLU disposal site in the T-1 wellhead area and to T-6 hole, a ditch 1m deep was dug around the built objects in accordance with the DED, and radiation hazard signs were posted with warning signs in two languages.

a) "Entombment" at T6 site

b) Enclosing ditch at T1 site

Figure 6. Remediation results

Radiation Control

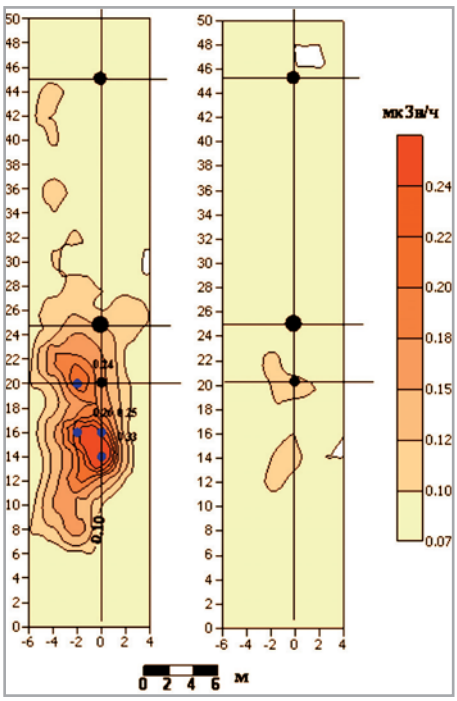
In the course of work performance, employees of INP NNC of the Republic of Kazakhstan conducted radiation control over the radiation environment of the objects. No radiation background exceeding the natural background level was revealed. Pursuant to section 15 of the Sanitary Rules for liquidation, conservation and conversion of radioactive ore mining and processing companies (CP KKP – 98) N 5.01.012.98 *, immediately after completion of all works, the post-remediation control was carried out, including radiometric survey of the reclaimed lands, collection and laboratory analysis of samples to determine the concentration of radionuclides. The purpose of such control was to evaluate the efficiency of measures taken.Figure 7 shows the results of radiation control on T1 site (RCS-1). The cartogram shows

that radiation characteristics after site remediation match the background values. Specific activity of natural radionuclides corresponds to the background values, and specific activity of Cs-137 and Am-241 corresponds to the values of global fallouts in this region (Table 3).

Table 3.

Gamma-spectrometry of soil samples taken at the reclaimed land on RCS-1 site (Bq/kg)

Sample	^{137}Cs	^{241}Am	^{210}Pb	^{226}R	^{214}Pb	^{214}Bi	234Th	^{232}Th	^{40}K
US-01	4.8	< 0.7	35.5	29.3	29.2	29.4	27.4	25.3	515
US-02	6.2	< 0.9	28.1	28.1	27.6	28.6	29.1	26.5	484
US-03	16.0	< 0.7	36.5	26.5	25.9	27.1	25.0	26.7	465
US-04	2.2	< 1.0	35.0	27.0	26.5	27.5	25.0	31.1	563
US-5	9.5	< 0.8	56.4	29.7	28.9	30.4	23.5	29.4	516



a) b)

Figure 7. Gamma field cartogram for RCS-1 area
a) – before remediation, b) –after remediation

CONCLUSION

Remediation works on nuclear test sites in the areas of Akotty, Mulkaman, and Kindikty resulted in elimination of the source of environment contamination and brought the radiological conditions at the reclaimed lands to the background level typical to this region. According to the principle of optimization stated in NRB- 99 radiation safety standards, only locally contaminated spots were disposed and buried without disturbance of soil or vegetation cover in the surrounding areas. The performed works contribute to the reduction of social tension by reducing radiophobia among people engaged in business activities in the surrounding areas.

These actions may serve as the basis for remediation measures in other locations of underground nuclear explosions.

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ҮСТІРТ ЖОНЫНДАҒЫ ЯДРОЛЫҚ СЫНАҚТАРДЫҢ ЗАРДАПТАРЫН ЖОЮ

Полешко А.Н., Глущенко В.Н., Лукашенко С.Н., Севериненко М.А., Николаев И.М., Левашов М.А., Глущенко Г.М., Мильц О.С., Резникова Р.А.

ҚР ҰЯО Ядролық физика институты, Алматы, Қазақстан

Мақалада, Үстірт жонындағы бейбіт ядролық жарылыстар өткізілген Ақтоты, Мүлкаман, Кіндікті жерлеріндегі, радиоактивті ластануды бағалау жұмыстары, жобаландыру және рекультивациялық орындау жұмыстары енетін, табиғатқорғау шаралар кешенін өткізу нәтижелері келтірілген. Ядролық жарылыстардың параметрлердің сипаттамасы келтірілген. Рекультивациялық жұмыстарға қолданатын технологиялар қарастырылған. Рекультивациялық бақылаудан кейінгі нәтижелердің негізінде, қазіргі уақыттағы радиациялық ахуал санитарлық-гигиеналық нормативтердің бекітілген шегінен аспайды. Радиациялық қатерлердің төмендеу технологиясы мен әдістерін қолдану тиімділігі туралы түйін жасалды.

ЛИКВИДАЦИЯ ПОСЛЕДСТВИЙ ЯДЕРНЫХ ИСПЫТАНИЙ НА ПЛАТО УСТЮРТ

Полешко А.Н., Глущенко В.Н., Лукашенко С.Н., Севериненко М.А., Николаев И.М., Левашов М.А., Глущенко Г.М., Мильц О.С., Резникова Р.А.

Институт ядерной физики НЯЦ РК, Алматы, Казахстан

В статье представлены результаты проведения комплекса природоохранных мероприятий в местах проведения мирных ядерных взрывов на плато Устюрт в местностях Актоты, Мулькаман, Киндикты, включающего оценку радиоактивного загрязнения, проектирование и выполнение рекультивационных работ. Приведено описание параметров ядерных взрывов. Рассмотрены применяемые технологии рекультивационных работ. На основании результатов после-рекультивационного контроля показано, что современная радиационная обстановка не выходит за пределы установленных санитарно-гигиенических нормативов. Сделан вывод об эффективности примененных методов и технологий снижения радиационных рисков.

УДК 577.4: 521.039.9:539.16

RADIOECOLOGICAL CONSEQUENCES OF THE UNDERGROUND NUCLEAR EXPLOSION "MERIDIAN-3"

Solodukhin V.P., Poznyak V.L.

Institute of Nuclear Physics NNC RK, Almaty, Kazakhstan

The paper reports on the radiological survey and the study of elemental composition and ^{137}Cs contents in soil samples taken from the underground nuclear explosion site "Meridian-3" and from Syrdarya River basin. The methods of radiometry, neutron activation analysis, XRF and γ-spectrometry were used. It was found that the elemental composition of the soil in two kilometer area from the "Meridian-3" epicenter is largely consistent with the composition of soil on the bank of Syrdarya River along its entire channel. However, ^{137}Cs concentration at this site and in the bank ground adjoining segment of Syrdarya significantly exceeds the background. These results provide a basis for the assumption that nuclear explosion at "Meridian-3 was followed by emission of such noble gases as ^{137}Xe, which caused a slight additional contamination of surrounding areas with artificial radionuclide ^{137}Cs.

The underground nuclear explosion "Meridian-3" was performed for the USSR Ministry of Geology on 15th of August 1973 in Shymkent region 90 km to south-west from Turkestan. The explosion was done with the purpose of the earth crust seismic sounding in order to reveal geological formations promising for minerals prospecting. The explosion was carried out at the depth 600 m, explosion power – 6.3 kt. Seismic magnitude was of 5.3. The explosion has been classified as one of total camouflet. It is pointed that no mining-and-geological, geophysical, radioecological, and other documentation concerning this object was provided to the Republic of Kazakhstan by Russian Federation. Information on geographical coordinates of this explosion is absent in the published materials.

Since 2004, the works on a more precise identification of the explosion epicenter, testing its territory and revealing its influence on the radioecological situation in Syrdarya river, the main freshwater artery of this region, were performed by the INP NNC RK.The geographical coordinates of "Meridian-3" nuclear explosion site were defined as follows: 42°46′27″ of Northern latitude and 67°24′25″of Eastern longitude. Radiometric investigations and soil samplings for laboratory studies were performed on the territory of 2 km from the explosion epicenter. It was found that for the whole researched territory the EDR remains within the background value range of (0.12 – 0.20) μSv/h. Soils of 0-5 cm were taken along 6 rays in 100 m, 1 km, and 2 km. Total 18 surface soil samples were taken. Besides, two 50 cm-deep trenches were laid along 2 rays (north and north-west directions) in 100 m from the explosion epicenter. Also there were taken soil samples (5 samples from each trench) in each 10 cm of depth for further laboratory researches.

Elemental composition in all taken soil samples was investigated using the methods of neuron activation analysis (NAA) and X-ray fluorescence analysis (XFA). Concentrations of more than 30 elements were calculated. Obtained data say that the elemental composition of the taken soil samples (0-5 cm) mostly correspond to the average value of soil composition on the bank of Syrdarya River. There are exceptions for some elements (Sc, Co, As, Sb, Cs, Ba, Pb, Th) for which the concentration are a little bit (20-30%) greater at "Meridian-3"site

than those on the bank of the river. Concentrations for the most of the target elements in soil layer of 10-40 cm is noticeably (30-50%) greater than those in the surface layer (0-10 cm), see Table 1. Probably, this peculiarity is the result of land reclamation performed on the territory.Radionuclide composition of soil has been studied by the method of instrumental γ-spectrometry. The results are presented at Figure 1 and in Tables 2, 3.

It was found that the average concentration of ^{137}Cs artificial radionuclide in the soil layer (0-5) cm on this site is (9.0 ± 3.1) Bq/kg (see Table 2). Based on our data, ^{137}Cs background concentration in this region is about 4 Bq/kg. Thus, the average concentration of ^{137}Cs artificial radionuclide in two kilometer area from the "Meridian-3" epicenter is noticeably greater that the background value.

Table 1.

Average concentrations for some elements in different soil layers at "Meridian-3" site, μg·g^{-1}

Soil layer, cm	Sc	Co	Zn	As	Sb	Cs	Ba	Pb	Th	U
0-10	10.3	10.1	68	10	1.4	5.7	690	18	8.6	2.0
10-20	13.5	14.0	85	14	1.9	8.1	840	24	10	3.1
20-30	14.0	14.5	92	15	1.9	8.9	770	25	11	4.8
30-40	13.0	14.0	90	15	1.8	8.2	750	26	12	4.8
40-50	8.3	8.0	53	7.5	1.3	4.3	690	20	8.2	2.5
$\overline{C}$	11.8	12.1	78	12.3	1.7	7.0	748	23	10	3.4
$\overline{C}$ for Syrdarya River	8.5	9.2	81	7.6	1.1	4.3	590	18	8.0	3.1
Clarkfor soil	7.0	8.0	50	5.0	1.0	5.0	500	10	6.0	1.0

Data presented in Table 3 showthat the most contaminated with ^{137}Cs artificial radionuclide are north-western and south-eastern directions from the explosion epicenter. Inthe case when the explosion wasaccompanied by outflow of precious gases, their propagation in one of these directionsis mostly probable.

Table 2.

Average^{137}Cs concentrationson different distances (R) from the explosion epicenter and spherical sites of different areas (S_R)

R, S_R	R – 100 m	R – 1 km	R – 2 km	S_R – 100 m	S_R – 1 km	S_R – 2 km
^{137}Cs, Bq/kg	8.0 ± 1.5	10.2 ± 4.5	9.0 ± 4.0	8.2 ± 1.4	9.0 ± 2.7	9.0 ± 3.1

Table 3.

Average^{137}Cs concentrations in different directions (rays) from the explosion epicenter

Direction	N (north)	NE (north-east)	SE (south-east)	S (south)	SW (south-west)	NW (north-west)
^{137}Cs, Bq/kg	7.4 ± 2.1	6.0 ± 1.3	11.0 ± 1.3	7.0 ± 0.8	8.7 ± 4.4	12.8 ± 5.3

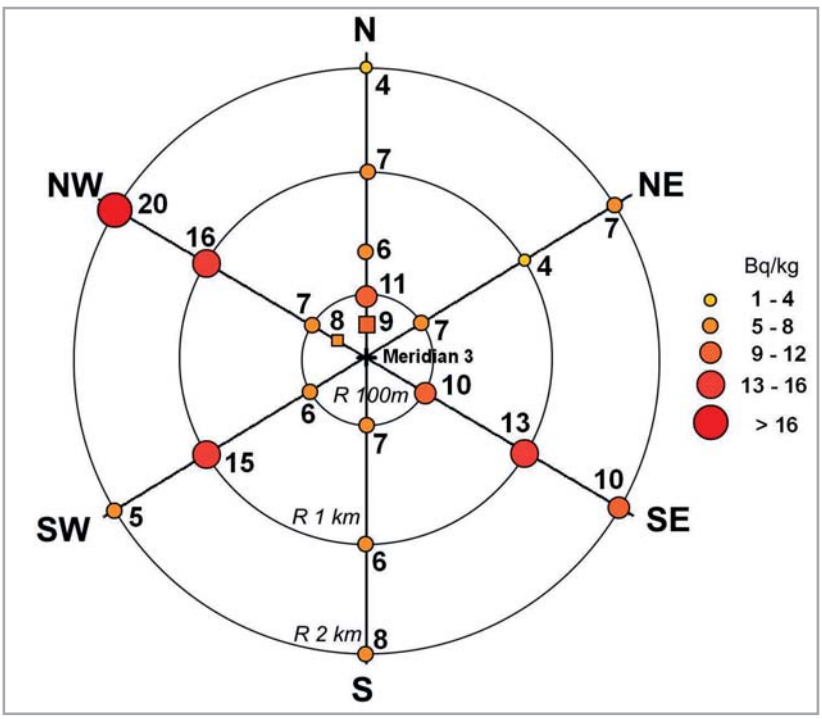

Figure 1. ^{137}Cs distribution in "Meridian-3" nuclear explosion epicenter area, Bq/kg.

Concentrations of ^{137}Cs in the riverbank soil have been studied for Syrdarya and its tributaries Keles and Kurkeles, Badam and Arys. Distribution of this radionuclide showed high heterogeneity what imposes difficulties on precise determination of its average value. In order to improve the statistics and reliability of the results we therefore assessed ^{137}Cs average concentrations for separate long spans along theserivers. Based on these calculations we plotted ^{137}Cs distribution for the Syrdarya river basin (Figure 2).

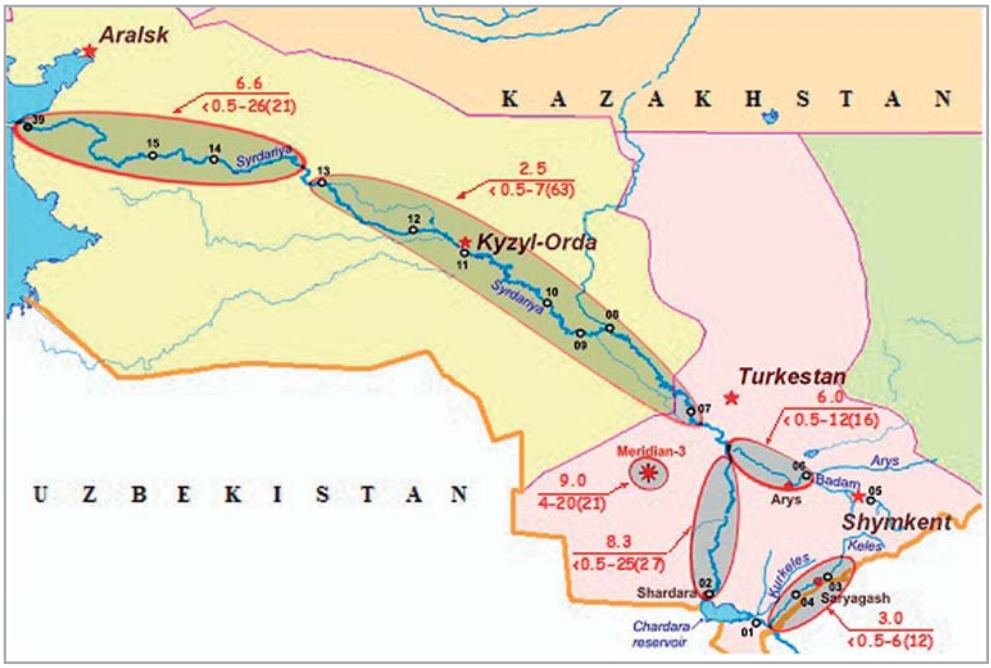

Figure2. ^{137}Cs distribution in Syrdarya riverbed, Bq/kg (soil layer 0-5 cm)

^{137}Cs distribution diagram along the Syrdarya riverbed is presented on Figure 3 below.

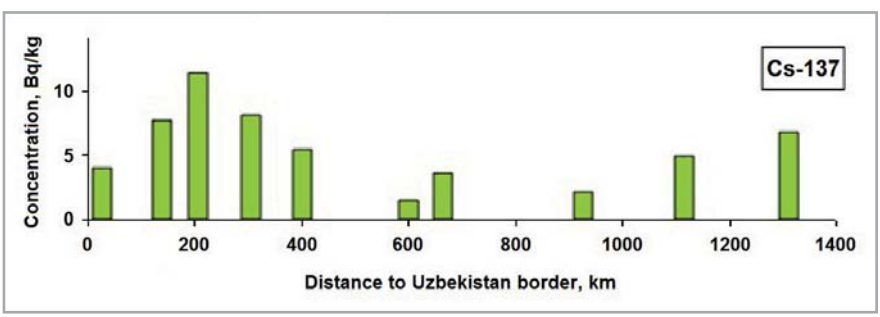

Figure3. ^{137}Cs distribution along the Syrdarya riverbed soil

Each particular value on this diagram is an average over not less than 10 data entries. The data on the diagram demonstrate that the band most close to the epicenter of the nuclear explosion (50-100 to the south-east) has maximal average concentration of the radionuclide which reaches 8.3 Bq/kg.

Performed studies make it possible to preliminary conclude that the nuclear explosion at Meridian-3 site resulted in release of noble gases and, particularly ^{137}Xe, what in its turn lead to some additional contamination of the neighboring areas with artificial ^{137}Cs.

Toverifythisstatement, more thorough investigation in compliance with standard procedures is required.

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«МЕРИДИАН-3» ЖЕРАСТЫ ЯДРОЛЫҚ ЖАРЫЛЫСЫНЫҢ РАДИОЭКОЛОГИЯЛЫҚ САЛДАРЫН ЗЕРТТЕУ

Солодухин В.П., Позняк В.Л.,

ҚР ҰЯО Ядролық физика институты, Алматы, Қазақстан

«Меридиан-3» жерасты ядролық жарылысының аумағынан және Сырдария бассейнінен іріктелген топырақтың сынамаларындағы ^{137}Cs құрамы мен элементтік құрамын зерделеу және радиациялық зерттеу нәтижелері келтірілген. Радиометрия, НАА, РФА және γ-спектрометрия әдістері пайдаланылды. «Меридиан-3» эпиорталығынан екікилометрлік аймақта топырақтың элементтік құрамы Сырдария өз. жағалауында оның барлық арнасы бойымен алынған топырақтың құрамына едәуір сәйкес келетіні анықталды. Сонымен қатар, бұл нысанның аумағындағы ^{137}Cs құрамы және оған Сырдария өз. қосылатын бөлігінің жағалаудағы топырағында оның аялық мәнінен едәуір жоғары. Алынған нәтижелерден, «Меридиан-3» нысанындағы ядролық жарылыстың соңы байытылған газдардың бөлінуімен ұласты, оның ішінде ^{137}Xe бөлінді, бұның нәтижесінде ^{137}Cs жасанды радионуклидімен маңайдағы аумақтың қосымша түрде болмашы ластануына алып келді деп болжам жасауға негіз болады.

ИЗУЧЕНИЕ РАДИОЭКОЛОГИЧЕСКИХ ПОСЛЕДСТВИЙ ПОДЗЕМНОГО ЯДЕРНОГО ВЗРЫВА «МЕРИДИАН-3»

Солодухин В.П., Позняк В.Л.,

Институт ядерной физики НЯЦ РК, Алматы, Казахстан

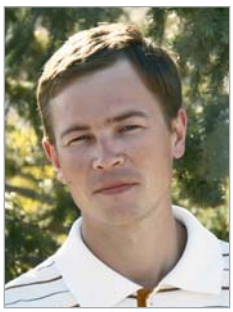
Приведены результаты радиационного обследования и изучения элементного состава и содержания ^{137}Cs в пробах грунта, отобранных на территории подземного ядерного взрыва «Меридиан-3» и в бассейне р. Сырдарья. Использованы методы радиометрии, НАА, РФА и γ-спектрометрии. Установлено, что элементный состав грунта в двухкилометровой зоне от эпицентра «Меридиан-3» в значительной степени соответствует составу грунта на побережье р. Сырдарья вдоль всего ее русла. Вместе с тем, содержание ^{137}Cs на территории этого объекта и в прибрежном грунте примыкающего к нему отрезка р. Сырдарья заметно превышает его фоновое значение. Полученные результаты дают основание для предположения о том, что ядерный взрыв на объекте «Меридиан-3» сопровождался истечением благородных газов, в частности ^{137}Xe, что и привело к незначительному дополнительному загрязнению окрестных территорий искусственным радионуклидом ^{137}Cs.

AUTHOR INDEX

ABOUT THE PRINCIPAL AUTHORS

Lukashenko S.N. graduated from Leningrad Institute named after Lensovet majoring in radiation chemistry in 1986 and was assigned to Institute of Nuclear Physics under Academy of Sciences of the Kazakh SSR, where he worked until 2006. In 2006 he was appointed Deputy Director General for Radioecology NNC RK and Director of the Institute of Radiation Safety and Ecology NNC RK. His main scientific interests lied in different years in the following areas: development of methods for elemental and radionuclide analysis, development of methods for radiochemical separation of radioactive isotopes, research/determination of conditions and states of various radiation-hazardous facilities, including former nuclear test sites Semipalatinsk and Azgir, venues of peaceful nuclear tests (LIRA site, Batolit, Region, and other), nuclear reactor facilities (reactor plant BN-350, Aktau, research reactor WWR-K, Almaty), sites of uranium mining and uranium processing facilities (tailings Koshkar-Ata, waste repository from UMP, etc.), facilities and areas with high natural radiological characteristics.

He has a long record as a manager/supervisor in major national and international projects. In 2006 he became a member of the Consultative Group on Nuclear Applications at the Director General of the International Atomic Energy Agency. He is a Co-author in over 110 scientific publications.



Turchenko D.V. graduated from Tomsk Polytechnical University in 2006 majoring in nuclear reactors and power facilities. In the same year he joined the Kurchatov's branch of the Institute of Nuclear Physics as an engineer-physicist in the Group of spectrometry and radiometry. In 2006 – 2010 he took part in various state and commercial projects aimed at conservation of radiation-hazardous sites and objects at STS. In 2010 he was appointed as a Head of the Group of spectrometry and radiometry at the Department of the monitoring systems development for environment of the IRSE and since that he is involved in research air basin pollution at radiation-hazardous sites of STS and in adjacent territories.

Poleshko A.N. graduated from Kazakh Polytechnical University in 1975 majoring in Geophysical methods to prospecting and exploration of minerals. In 1975-1998 he was involved in development and implementation of the methods for x-ray radiometry of rocks and ores in nature. Since 2001 he works for the Institute of Nuclear Physics currently occupying the position of the Deputy Head of the center for Complex Ecology Research. His main focus is on monitoring of radiation conditions and states, lowering of radiological hazards in the places of historical contamination at sites influenced by radiation-hazardous facilities. He is a co-author in more than 30 scientific publications.

Solodukhin V.P., Doctor of Sciences in physics and mathematics; he has being working for the Institute of Nuclear Physics for 50 years, since 1963 after graduation from the Department of Physics of S.M.Kirov KazSU. He is the pupil of laureate of Lenin's and State awards of USSR V.V. Sokol'sky. During his work in the Institute he took positions from an engineer up to Deputy Direcotr. Currently he is the Leading scientist and the Scientific Head of the Center for Complex Ecology Research of the Institute. He is a specialist in nuclear-physical analysis methods in Radioecology. He is an organizer and leader in several international collaborative projects such as ISTC Project K-053 "Characterization of radiological and non-radiological contaminants at Semipalatinsk Test Site", ISTC K-337 "Development of the Basis and Choice of the Technology for Removal of Surface Contamination and Techniques for Limiting Secondary Contamination of the SNTS Territory", ISTC Project K-884 ""Investigation of the Sources and Mechanisms of the Radionuclides and Toxic Elements Contamination in Syrdarya River Basin at the Territory of the Republic of Kazakhstan", IAEA Project K-201 "The Activation analysis laboratory" and a range of other projects.

Solodukhin V.P. has got author certificates and as a co-author patented "The method for extraction and concentration of plutonium and americium from soils of Semipalatinsk Nuclear Test Site". He is a co-author in discovery of 5 vanadium deposits in oilfields in Volga River region. As an expert in radiation safety he audits uranium mines. For more than 8 years he was a member of the USSR Scientific Council for application of nuclear physical methods in cross-disciplinary areas leaded by Academician Flerov G.N. and later by USSR corresponding member Mostov V.I. Currently he is a member of International Radiochemical Society, Scientific Council of INP NNC RK.

Solodukhin V.P. is a co-author of the monograph "Metalls in Oil" and in more than 250 scientific publications. His works were reported at more than 50 International, All-Union, and State conferences and workshops.

Lyakhova O.N., Graduated from the Department of Physics of East-Kazakhstan State University in 2000 majoring in spectroscopy and joined the IAE NNC RK as an engineer-physicist in the laboratory for Radiation Research and Migration of Decay Products. Since 2006 she works for IRSE NNC RK in the "Department of the monitoring systems development for environment". Currently she leads the Laboratory for experimental studies of transfer mechanisms. Her main focus is on studies of the level and character of tritium distribution in atmospheric air at nuclear test sites, tritium distribution is various environmental systems "water-atmosphere", "soil-atmosphere", "underground waters-atmosphere", "vegetation-atmosphere". She is an author in more than 15 publications in the field.

Larionova N.V. graduated from Shakarim Semipalatinsk State University in 2003 with a degree in biology and in 2006 with MS degree in ecology from the same university. Since 2003 she has been working for IRSE; currently she leads the laboratory for radioecological studies in the Department for Integrated Ecosystem Studies. Her research interests lie in field experiments to study redistribution of radionuclides in the system "soil-plant" and in assessment of radioactive contamination nature for vegetation at STS. She is a co-author in more than 30 scientific papers.

Kozhakhanov T. Ye. In 2004 he graduated with honors from Shakarim Semipalatinsk State University with degree in ecology. In 2006 he completed MA program at Semipalatinsk State Pedagogical Institute and obtained MS degree in ecology. In April of 2010 he was appointed to the position of an engineer (with no experience required), in the Department for ecosystems' integrated research, in the Institute of Radiation Safety and Ecology. In September of 2012 he was promoted to the position of the Head of the Department, Radioecology of Agricultural Plants, Ecosystem Integrated Researches Department. He is currently engaged in developing tests and field testing of agricultural crop plants to explore the redistribution of radionuclides within the "soil-plant" system and to assess the nature and extent of radioactive contamination that the vegetation of STS is exposed to. He is part of expedition activities under State research program"038". He took part in the R&D contest for junior scientists and specialists of NNC, Kazakhstan, the "Nuclear and Radiation Physics" international conference held in Almaty, and the V international research-to-practice conference known as "Semipalatinsk Test Site. Radiation Legacy and Prospects for Development" held in Kurchatov. In 2012 he completed training on "Radiation safety when handling radioactive substances". He does the research "Features of artificial radionuclides' transfer in the crop products planted on Opytnoye Pole testing ground of STS."

Kunduzbayeva A.Ye. In 2002 she graduated from Shakarim Semipalatinsk State University in and obtained degree in chemistry; then in 2004 – MS degree majoring in High-molecular compound chemistry. She works for IRSE since 2004 and currently occupies the position of an engineer in the Department of Ecosystem Integrated Research. She studies the behavior of artificial radionuclides in soil. She is a co-author in 10 scientific publications.

Baigazinov Zh.A. In 2006 he graduated from Shakarim Semipalatinsk State University in and obtained degree with honors majoring in Selection and biotechnology for livestock farming, then in 2008 got his MS degree in biology from Semipalatinsk State Pedagogical Institute. He works for IRSE since 2006 and currently leads the Group for Radioecology of agricultural animals. His main scientific interests are focused on agricultural radioecology and radiation biology of agricultural animals and birds.

He studies distribution of the radionuclides (^{137}Cs, ^{90}Sr, ^{241}Am, $^{239+240}$Pu, ^{3}H) in organs and tissues of agricultural animals and birds, peculiarities of metabolism, transfer of the radionuclides to products of cattle, sheep, horse breeding and aviculture; radioecological assessment of pasture and hayfields at contaminated with radiation lands of former STS and assessment of possibilities for livestock farming at those lands.

He is an author in more than 30 scientific papers and abstracts.

Romanenko V.V. In 2008 he graduated from the Engineering and Technology Department of Shakarim Semipalatinsk State University with degree in Technical Physics. In the same year he started his career to work as an engineer at the Institute of Atomic Energy, NNC, Kazakhstan. He has been working for the Institute of Radiation Safety and Ecology since 2011 as a team leader in the Laboratory for geoinformation technologies. The main field of activity is study of effects and consequences of underground nuclear explosions, radiation safety assurance for activities under the risk of radioactive contamination.

Shatrov A.N. Graduated in 2008 from a MS program in radiation physics of Tomsk State University. After that he joined the spectrometry team in the Institute of Radiation Safety and Ecology and currently occupies the position of the Head of the Group of Spectrometry Research. His scientific interests are focused on dose calculations for external and internal irradiation. He took part in a contest for junior scientists. In 2012 he got a silver award in radioecology for his work "Investigation of isotopic ratios of transuranium elements at Opytnoye Pole site".

Yagova A.Kh. In 1973 she graduated from St. Petersburg Mechnikov State Medical Academy. She has been working for the National Center of Radiobiology and Radiation Protection (Sofia, Bulgaria) since 1975.In 1979 she defended a thesis for the degree of a candidate of medical sciences on the mutagenic and teratogenic effects of tritium (tritiated water) in rats. She worked as a researcher in the Department of Radiation Genetics, the National Centre of Radiobiology and Radiation Protection.

From 1992 through 2010 she was the Headed of Department, Radiation Epidemiology.

In 2010 she was seconded to the LRB, JINR.

Her key research interests relate to the study of conformity to biological effects of ionizing radiation, the influence of a number of radionuclides on the somatic and germ cells of mammals, the study of chromosome aberrations in human peripheral blood lymphocytes and their biological consequences, the analysis of occurrence of cancer in workers of the nuclear industry and medicine, as well as in people residing in some areas of Bulgaria after the Chernobyl Nuclear Power Plant disaster.

She is an author in 59 scientific papers.

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