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The book presents the activities of the National Nuclear Center of Kazakhstan for 2010. The articles reflect the issues of radioecology in the former Semipalatinsk Test Site (STS) and adjacent areas, other sites of nuclear testing in Kazakhstan (site "Azgir", "LIRA" facilities), assurance of safe works at STS, reports on special studies and research of "non-radiological" hazards at STS. The authors believe that the proposed issue will allow each reader to gain reliable information about current state of all major facilities in Kazakhstan where nuclear tests were conducted.

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Dedicated
to the 20th Anniversary
of the Independence
of the Republic of Kazakhstan
and
to the 20th Anniversary
of the closure
of the Semipalatinsk
Nuclear Test Site

FOREWORD FROM THE EDITOR

Since establishment of the National Nuclear Center of Kazakhstan (NNC RK) the radioecology has reasonably become one of the main activities of the Center. In 1991 the Semipalatinsk Test Site was closed, the country gained its independence, but along with gaining the independence, we inherited the problems which previously the scientists in Kazakhstan were not involved in; first of all, these were the problems at former nuclear test sites and sites of peaceful nuclear tests.

What did radioecology in NNC RK start with? With a bunch people in the Institute of Nuclear Physics (INP) and the Institute of Atomic Energy (IAE), experts in nuclear physics, neutron activation, trace element analysis, nuclear spectroscopy, radiochemistry, radiation safety, but not in radioecology. The only basic equipment we had was a homemade alpha-camera, a couple of obsolete gamma-ray spectrometers, radiometers and dosimeters. That was actually all. The Institute of Radiation Safety and Ecology (IRSE) did not exist yet. In 1994, a big achievement was to get the first Kazakh-Russian-US contract for determination of $^{239+240}$Pu and Sr contents in *ten (!)* samples.

What represents radioecology in NNC RK today? Radioecology in NNC today – about 200 qualified professionals, based mainly in the INP and the IRSE, but not only this, it is also a park of the most advanced equipment to perform both routine analysis with high quality and sensitivity (determination, for example, of plutonium isotopes in thousands of samples per year), and specific types of studies: EPR-dosimetry, high-resolution mass-spectrometry, electron-microscopic examination of individual particles, in particular "hot" particles, and many more.

Appropriately, in 20 years a lot of radioecological problems have been resolved; many of the problems were of high social and national significance. Assignment of LIRA facilities under the NNC RK radiological control made it possible to develop the largest Karachaganak oil-gas condensate field (the readers will find an article on current conditions at "LIRA" facilities in this issue); development and organization of a monitoring system, land remediation at "Azgir" site allowed to assure comprehensive radiation safety of the site with drastic reduction in radio-phobia in the region (an article about "Azgir" site also can be found in the issue).

Of course, special attention has been paid to the former Semipalatinsk Nuclear Test Site (STS), one of three major nuclear test sites in the world where 456 nuclear explosions were carried out with a total capacity of 17.7 megatons, equivalent to almost 1,000 atomic bombs dropped on Hiroshima. By the time of the STS shutdown in 1991, no information about the real radiological situation was available in Kazakhstan.

During the period from 1991 to 2011 at the STS the National Nuclear Centre of Kazakhstan in cooperation with international organizations and research centers undertook extensive research and huge works to reduce the risks posed by the STS.

Extensive operations were accomplished on the elimination of the test site facilities. At Degelen site only, 181 tunnels (adits) were eliminated; protective measures were taken at Aktan-Berli site assuring no proliferation of radioactivity and its negative impact on the surrounding environment and population; part of the wells was eliminated at Balapan site, measures were taken to restrict physical access to the site of warfare radioactive agents testing. The complex of these works has resulted in significant reduction of risks at the STS.

The STS territory has been thoroughly studied by now. Virtually all the significant contamination areas, main pathways and mechanisms for current and potential proliferation of radioactivity have been revealed. One of the most important results was a new understanding that part of the STS territory is "clean" and can be used for commercial activities. The existing STS boundaries are obviously excessive and unreasonable in terms of radiation safety.

Moreover, given the immensity of the STS and diversity of the tests previously performed there, the available information is not comprehensive, but it allows us to offer a science-based work plan: a phased withdrawal of the STS territory from the reserve lands and their transfer to civilian use.

The STS lands are rich in minerals; in particular, there are deposits of coal, gold, nickel, iron, copper, etc. Large areas of the STS in fact have long been used as agricultural land, for example, for cattle grazing. Development of the STS is restrained both by its legal status and its negative image.

During 2008-2009, 3 000 km^2 on the "northern" territories of the STS (approximately 16% of the test site) were extensively investigated. Soils, vegetation, air basin and water environment, flora and fauna were studied; changes in the radiation situation were forecasted with advanced calculations. The findings and conclusions are based on experimental determination of approximately 20,000 parameters that characterize the radiation environment. Field experiments were carried out based on a specially organized "experimental farm" in order to obtain the most reliable data from the most polluted areas (sites "Degelen" and "Experimental Field"). The findings resulted in a monograph in Kazakh, Russian and English with the aim of informing the public and professionals: it became the first book in this series of books "Topical issues in Radioecology of Kazakhstan". The main conclusion was about the possibility for unlimited use of 2,997 km^2 in the "northern" territories of the STS. In 2009-2010, similar works were carried out on the "western" part of the STS in Karaganda Region within an area of 560 km^2. A conclusion was made about the possibility for unlimited use of the entire study area (an article with the results of studies is also available in this issue).

The Atomic Energy Agency (IAEA) was invited to conduct peer review of the results. The corresponding IAEA report says: "... Analytical methods used in the laboratories of NNC RK are the most advanced, the technical tools meet modern requirements, and the staff is highly qualified. Based on the works undertaken by the National Nuclear Center of Kazakhstan (NNC) and prepared report "Semipalatinsk test site: Radioecological Situation of the "northern lands" the following conclusions can be made. NNC RK completed a comprehensive assessment of the distribution of radioactivity in the northern territories. The procedure of sampling and analytical methods used in determining the radionuclides in environmental samples, are consistent with stated objectives of assessment. The contamination level of the northern territories, in general, is low and consistent with levels of global fallouts ..."

Thus, the works and analyses of the collected information about the STS make it possible to conclude that provided adequate attention from the State, the issues of the former Semipalatinsk Test Site can be radically resolved by the 30th anniversary of Independence of the Republic of Kazakhstan. By the radical solution to the STS problems the NNC RK means the following: anything which is clean and can be used in the national economy – should be used; those contamination spots that can reasonably be eliminated – should be eliminated, and sites or areas elimination of which is either impossible or impractical should be equipped with a comprehensive system of physical access restriction. *The administrative boundary of the STS should be consistent with its current radioecological status.*

The present book provides the results of the works conducted by the NNC RK mainly during 2010, but we hope that an attentive reading of even these works will enable an interested reader to make its own unbiased view of the real radioecological state of the most important radiation-hazardous facilities in the Republic of Kazakhstan.

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

PART: RADIOECOLOGICAL STATE OF THE FORMER SEMIPALATINSK TEST SITE AND ADJACENT AREAS

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CHARACTER AND LEVEL OF CONTAMINATION WITH RADIONUCLIDES AT THE "EXPERIMENTAL FIELD" SITE OF THE SEMIPALATINSK TEST SITE

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The "Experimental field" site (also known as *Opytnoye Pole*) is the first nuclear weapons site in the Soviet Union. No systematic investigations of its vast territory have ever been carried out there before.

To reveal the radiological situation and to make an inventory of radiation-hazardous objects, all the territory of the "Experimental field" site and the territory of technical sites P-1, P-2, P2-G, P-3, P-5 and P-7 located on it was studied. The study of technical sites implied identification of radiation-hazardous areas, pedestrian gamma-survey, investigation of areal and in-depth distribution of artificial radionuclides.

Integral radiation parameters show that only a small part of the "Experimental field" site can be considered as radiation-contaminated area. The area with EDR level exceeding 0.24 μSv/h is about 11 km^2, i.e. 3% of all territory of the "Experimental field" site.

Several spots were detected which can be identified as "epicenters" of nuclear explosions. As a rule, the soil in the epicenters and adjacent areas had high concentrations of artificial radionuclides. In radial direction, concentrations of artificial radionuclides (ARad) changed exponentially; at a distance of 300-500 m ARad concentrations practically decreased to the background values. At the same time, it should be noted that though all epicenters have some common characteristics, each epicenter has its own "radionuclide portrait" different from all others, primarily, by the concentrations of radionuclides and their isotopes. The areas with other types of contamination which can be called "areal" were also detected. The main mechanism that can explain the origin of such areas is superposition of fallouts of nuclear tests. The areas have conventionally uniform distribution of artificial radionuclides concentrations on the territories as large as tens of square kilometers.

The products of ^{137}Cs and ^{90}Sr decay spread in three directions – northeastern, southeastern and southwestern. The highest concentration corresponds to the epicenters of nuclear explosions. The radionuclide ^{241}Am and, hence, $^{239+240}$Pu is mainly registered in the epicenter zones of all technical sites, especially on P-2 and P-7 and beyond their areas as long traces of radioactive fallouts. In addition to fissile materials and fission products, the epicenters have elevated concentrations of neutron activation products: Co^{60}, Eu$^{152, 154, 155}$, which, mainly, do not leave the territory of technical sites.

Keywords: Semipalatinsk test site, experimental field, radiation situation, man-made objects, cesium, strontium, americium, plutonium, cobalt, europium, areal survey, radionuclide contamination, inventory, radiation-hazardous object.

INTRODUCTION

The "Experimental field" site was the main test site in the USSR for atmospheric and ground tests of nuclear weapons. The years of tests caused large-scale contamination of its territory [1]. Gamma-aero-photo-surveying (1990–1993) showed that the "Experimental field" site is contaminated with ^{137}Cs [7]. However, the results of that survey provided no information about other radionuclides, and low resolution of the technique used provided only a rough estimation of the general character of contamination. Within the ISTC projects K-54, K-337 [26, 7] investigations of the general character of the STS radioactive contamination were carried out, and contaminated spots on the technical sites P-2, P2-G and P-7 were described. The results of surveys were further used in selected areas for further detailed studies and construction of generalized maps of areal contamination.

It is very important to determine radiation parameters of the "Experimental field" site as the tests made on the site became the main source of contamination of the environment on the STS and surrounding territories.

The objective of this research is to perform a systematic investigation of the character and level of contamination of the soil at the "Experimental field" site which included:

- assessment of the state of the "Experimental field", the extent of man-caused disturbance of the natural landscape and description of technogenic objects;
- studying of mechanisms and peculiarities of radiological situation in the epicenters of technical sites;
- determination of the character and level of radionuclide contamination at some typical objects.

1. HISTORY OF TESTS ON THE "EXPERIMENTAL FIELD" SITE

The "Experimental field" site is a plain of 20 km in diameter surrounded by low mountains from three sides – southern, western and northern and located in the Irtysh-river steppe, 140 km to the west from Semipalatinsk. According to the official data [25], in the period from 1949 to 1962, 30 ground and 86 atmospheric tests were performed on the territory of the "Experimental field" site. Since atmospheric tests mainly cause stratosphere pollution and radioactive fallouts at long distances, further we will consider in detail only ground tests. 30 ground tests (including 5 tests without reaching the nuclear test regime) made at a small or zero height could cause maximal contamination of the STS territory and, especially the territory of the "Experimental field" site [1].

Tests at the "Experimental field" site were made on 6 technical sites P-1, P-2, P-3, P-5, P-7 [12] and P2-G [7]. No official information about the location of the site P-2G is available. It is supposed that it is located at the intersection of technical sites P-2 and P-7. Each site is an area with a radius of about 2 km without any special fence. There is information about some other technical sites on the "Experimental field", for example, P5-G and P-6, however, no information about nuclear tests on the sites is available.

The monograph [25] presents the data on power, dates and purposes of experiments, but it does not contain the data on the exact venues of tests and wind directions, i.e. the information that can be used to identify places and directions of radioactive fallouts. For this purpose we analyzed information from the other sources including bulletins of the RF Atomic Energy Public Information Center. Unfortunately, we could not find complete information on average wind directions, and different sources gave different data. Reference [22] provides graphical form the information about the directions of radioactive traces processed using geographic information systems (GIS). There is no information about the place of the test made on 30.10.62. Compiled data on the main characteristics of ground tests are given in table 1.

Table 1.

Main characteristics of ground nuclear tests

No.	Test date [12]	Test location (site) [12]	Test purpose	Power release, in kilotons of TNT equivalent	Explosion altitude, m	Average wind direction, degree [12]
1	29.08.49	P-1	MNW [12, 25]	22 [12, 25]	tower 30[12, 25,14]	74 75 [23]
2	24.09.51	P-1	MNW [12, 25]	38 [12, 25]	tower 30 [12, 25]	208*
3	12.08.53	P-1	MNW [12, 25]	400** [12, 25,14]	tower 30 [12, 25]	130 [14] 146*
4	05.11.62	P-1	IDF [12, 25]	0.4 [12, 25]	tower 15 [12, 25]	
5	19.10.54 (did not explode)	P-2	MNW [12, 25]	0 [12, 25]	tower 15 [12, 25]	
6	29.07.55	P-2	MNW [12, 25]	1.3 [12, 25,14]	2,5 [12, 25,14]	97 [14, 15] 80 [23] 69*
7	02.08.55	P-2	MNW [12, 25]	12 [12, 25,14] 11,5 [21]	2,5 [12, 25,14]	225*
8	05.08.55	P-2	MNW [12, 25]	1.5 [12, 25,14] 1,2 [21]	1,5 [12, 25,14]	65*
9	16.03.56	P-2	MNW [12, 25]	14 [12, 25] 13,2 [21]	0,4 [12, 25]	130*[22] 120 [23]
10	25.03.56	P-2	MNW [12, 25]	5.5 [12, 25]	1 [12, 25]	270*
11	05.10.54	P-3	MNW [12, 25]	4 [12, 25]	0 [12, 25]	210*
12	22.09.62	P-3	IES [12, 25]	0.21 [12, 25]	0 [12, 25]	
13	11.11.62	P-3	MNW [12, 25]	0.1 [12, 25,14]	tower 8 [12, 25,14]	98 98 [14, 15] 53*
14	30.10.54	P-3	MNW [12, 25]	10 [12, 25]	Bombing from plane with blasting at 50m [12, 25]	
15	24.08.56	P-5	MNW [12, 25]	27 [12, 25,14] 26,5 [12, 25]	tower 100 [12, 25,14]	105 [14, 15] 100 [23]
16	07.08.62	P-5	MNW [12, 25]	9.9 [12, 25,14]	0 [12, 25]	80 72 [14, 15] 60 [23]

No.	Test date [12]	Test location (site) [12]	Test purpose	Power release, in kilotons of TNT equivalent	Explosion altitude, m	Average wind direction, degree [12]
17	25.09.62	P-5	MNW [12, 25]	7 [12, 25]	0 [12, 25]	100* [22] 90 [24, 23]
18	09.09.61	P-7	IES [12, 25]	0.38 [12, 25,14] 0,4 [21]	0 [12, 25]	60 70 [14] 75 [15, 23] 55*
19	14.09.61	P-7	MNW [12, 25]	0.4 [12, 25]	0 [12, 25]	60*
20	18.09.61	P-7	IES [12, 25]	0.004 [12, 25]	1 [12, 25]	55*
21	19.09.61	P-7	IES [12, 25]	0.03 [12, 25]	0 [12, 25]	
22	03.11.61 (did not explode)	P-7	IES [12, 25]	0 [12, 25]	0 [12, 25]	
23	04.11.61	P-7	MNW [12, 25]	0.2 [12, 25,14] 0,15 [21]	0 [12, 25]	104 104 [14, 15]
24	13.11.62 (did not explode)	P-7	MNW [12, 25]	0 [12, 25]	0 [12, 25]	
25	24.11.62 (did not explode)	P-7	IES [12, 25]	0 [12, 25]	0 [12, 25]	
26	27.11.62	P-7	IES [12, 25]	0.03 [12, 25]	0 [12, 25]	80 80 [23] 88 [14]
27	23.12.62 (did not explode)	P-7	IES [12, 25]	0 [12, 25]	0 [12, 25]	
28	24.12.62	P-7	IES [12, 25]	0.007 [12, 25]	0 [12, 25]	40-100 40 [24]
29	24.12.62	P-7	IES [12, 25]	0.028 [12, 25]	0 [12, 25]	40 40 [23]
30	30.10.62	-	MNW [12, 25]	1.2 [12, 25]	0 [12, 25]	

Note: * - calculated using graphical information; ** - thermonuclear experiment;
MNW – tests on modernization of nuclear weapons;
IES – investigations of emergency states and situations;
IDF – investigations of damaging factors of nuclear explosions and their impact on military and civil objects action.

In the period from 1958 to 1963, 40 hydronuclear explosions with different amount of nuclear power released to the atmosphere and different height of the upper rim of the explosion cloud were made on the site P2-G [3]. Hydronuclear tests are explosions with nuclear charges where the amount of released nuclear energy is comparable with the energy of chemical explosives. In such experiments the compressibility of fissile materials under shock-wave impact of the energy of explosive substances and fallout of alpha-active radionuclides, a part of nuclear charge, on the soil surface were studied [7]. In such experiments the fissile nuclear substance is so compressed by the explosion in the shell of chemical explosives that plutonium loses its mechanical hardness and behaves like a liquid. At the same time, the explosion energy must not be so high that it could turn plutonium into plasma needed to initiate chain reaction. As fissile materials plutonium and uranium were used [31].

Total amount of plutonium alpha-activity of dispersed during hydronuclear experiments was about 800-900 Curie, which could cause severe contamination of the "Experimental field" site and the area around the site [3]. The main characteristics of hydronuclear tests are presented in Table below, [29].

Table 2.

Characteristics of model experiments on the site P2-G

No.	Date	Relative power release in the explosion, t	Average wind speed (km/h) during the explosion at heights h=0-1 km	Azimuth direction of the trace axis (degrees);	Type
1 [3]	13.03.58	-	-	-	A
2 [3]	15.03.58	-	-	-	A
3	20.05.60	1	18	142	G
4	22.05.60	1	11	328	G
5	24.05.60	1	14	137	G
6	26.05.60	1	14	65	G
7	31.05.60	1	29	81	G
8	01.06.60	1	18	102	G
9	06.06.60	1	50	68	P
10	08.06.60	1	47	81	P
11	10.06.60	1	72	74	P
12	11.06.60	1	25	52	P
13	13.06.60	1	7	209	P
14	16.06.60	1	29	86	P
15	27.06.61	1	25	304	G
16	29.06.61	1	25	132	G
17	01.07.61	1	11	143	G
18	04.07.61	1	43	342	G
19	06.07.61	1	32	70	G
20	08.07.61	1	47	93	G
21	13.07.61	1	29	83	G
22	15.07.61	1	7	104	G
23	20.07.61	0.35	7	173	P
24	21.07.61	0.35	18	200	P
25	22.07.61	0.35	25	79	P
26	22.07.61	0.35	25	162	P
27	24.07.61	0.35	40	338	P
28	19.09.63	1	43	68	P
29	20.09.63	1	29	113	P
30	24.09.63	1	13	94	P
31	25.09.63	0.35	47	93	P
32	26.09.63	0.35	32	153	P
33	30.09.63	0.35	18	223	P
34	01.10.63	0.35	11	232	P
35	02.10.63	0.35	14	226	P

No.	Date	Relative power release in the explosion, t	Average wind speed (km/h) during the explosion at heights h=0-1 km	Azimuth direction of the trace axis (degrees);	Type
36	10.10.63	0.35	24	79	P
37	11.10.63	0.35	40	84	P
38	12.10.63	0.35	25	137	H=3 m
39	12.10.63	0.35	14	123	P
40	15.10.63	0.35	14	104	H=3 m
Note: Type – explosion type. «A» - atmospheric, bombing from plane; «G» -ground explosion; «P» - explosion in the pit; H=3m – explosion on the support (tree) at a height of 3m from the ground					

On the technical sites P-2 and P-7, located in southern part of the "Experimental field" site, besides nuclear tests hydrodynamic tests, explosive experiments with nuclear charges in which no nuclear energy was released, were performed [1, 3, 30]. In the period from 1954 to 1962, 5 such tests were performed; as a result 1,000 Ci of plutonium were released to the atmosphere. The main characteristics of hydrodynamic tests are presented in Table below.

Table 3.

Characteristics of hydrodynamic experiments on technical sites P-2 and P-7 [1,29]

Number of experiment	Date	Amount of Pu alpha-activity dispersed in the explosion, Ci	Azimuth direction of trace axis (degrees)	Average wind speed, m/s
1	19.10.54	200-400	18	8.3
2	03.11.61	200-400	213	3.5
3	13.11.62	200-400	176	3.3
4	24.11.62	100-200	320	6.1
5	23.12.62	200-400	296	4.5

All the above experiments could, to a higher or smaller extent, cause contamination of the studied area and the area beyond the boundaries of the "Experimental field" site. An analysis of the available data on the average wind direction during the tests enabled to determine directions of most traces of radioactive fallouts from ground nuclear, hydronuclear and hydrodynamic tests (figure 1).

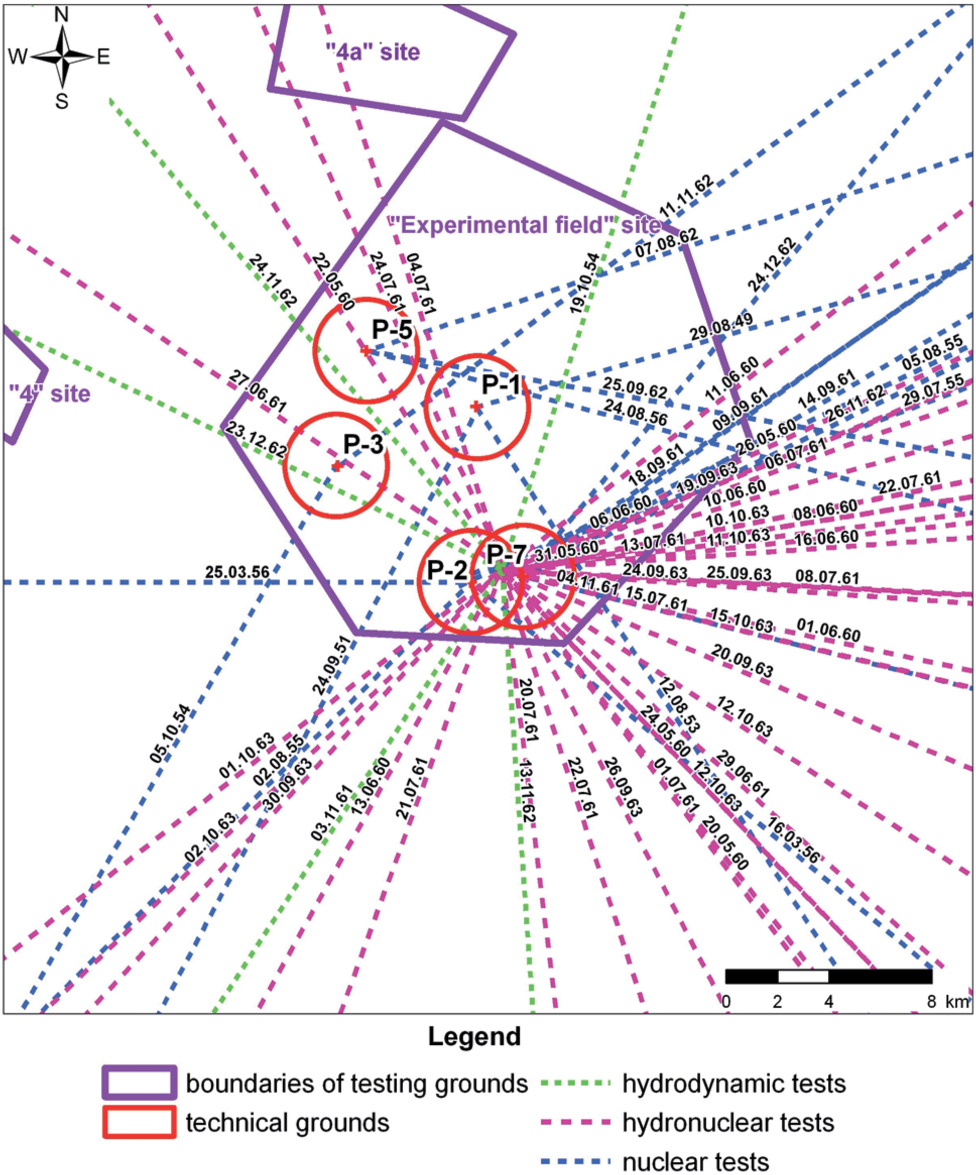


Figure 1. Main directions of average winds during nuclear, hydronuclear and hydrodynamic tests

Radioactive contamination of the site may include the following groups of artificial radionuclides:

- radionuclides formed as a result of fission of fissile substances nuclei (fission fragments ^{90}Sr, ^{137}Cs , ^{151}Sm and ^{99}Tc);
- fragments of fissile substance ($^{239+240}Pu$, ^{238}Pu, ^{241}Pu and ^{241}Am), which have the highest level of radiotoxicity;

- radioactive isotopes – products of activation of environmental nuclei by fission neutrons ($^{152,154,155}Eu$ and ^{60}Co). They are probably concentrated directly in the epicenters.

An analysis of all initial information enables to make a conclusion that the priority objects of investigations must be epicenters of nuclear explosions and spots of possible fallouts of radioactive precipitations in southwestern, southern and southeastern directions with respect to sites P-2 and P-7. In this case, one should take into account the assumed high density of fallouts of ^{241}Am and, hence, $^{239+240}Pu$ in southern and southeastern parts of the "Experimental field" site.

2. EXPERIMENT

To detect technogenic objects on the territory of the "Experimental field" site we studied satellite images which enabled us to detect some objects including large epicenters. Field works were carried out to make an inventory of technogenic objects and to estimate the extent of technogenic disturbance of the landscape.

To study the radiation situation the "Experimental field" site was surveyed in a large-scale. The survey included determination of coordinates of 1083 points uniformly distributed on the 500×500 m grid on the site, measurement of radiation parameters – EDR and density of beta-particles flux, point soil sampling. The samples were first subjected to semi-quantitative analysis (sorting) in order to exclude cross-contamination of samples in their further processing. In order to determine concentration of artificial radionuclides ^{60}Co, ^{90}Sr,^{137}Cs, $^{152, 154, 155}Eu$ and ^{241}Am the samples further passed quantitative gamma- and beta-spectrometric analysis.

To estimate the character and level of contamination of some typical radioactively-contaminated areas in detail, the areal distribution of artificial radionuclides was studied. To estimate the character of vertical radionuclide distribution in soil profiles layered soil samples were taken in several typical points. The priority areas for detailed investigation were epicenter areas and radioactively-contaminated spots with EDR level equal or higher than 0.24 μSv/h.

2.1. General characteristics of the "Experimental field" site

2.1.1. General assessment, detection of technogenic objects

In order to estimate general state of the "Experimental field" site, to determine the extent of technogenic disturbance of natural landscape and to discover various man-made objects, the following works have been done:

- visual examination of the test site territory;
- analysis of the satellite image of the test site territory [18];
- reconnaissance survey of technical sites within the "Experimental field" site, which included visual examination of the place of works, visual estimation of relief, description of man-made objects and bare rocks, in particular, construction excavations, pits, etc.

2.2.2. Radiological situation at the "Experimental field" site

In order to determine location of points in the geographical coordinate system a satellite device of global positioning *Garmin Rino 520*, which can determine point position with accuracy of ±5m, was used. Preliminary, before measurements, the survey grid was calculated. Coordinates of the points in the grid were recorded by the GPS receiver and were determined in the navigation regime. The preparations to works and determination of coordinates were made according to the GPS user manuals [6].

Radiation parameters were measured in nodes of the survey grid according to the instructions of the dosimeter-radiometer MKS-AT6130 [9] and technique of gamma-background measurement of areas and premises [6]. EDR and density of beta-particle flux were measured on the area of 200 cm^2 to a depth of 5cm in each point. Soil samples were taken and packed according to the requirements to soil sampling for general and local contaminations [7].

To obtain the initial data and to exclude possible cross-contamination during further processing, the soil samples were sorted by measuring ^{241}Am and ^{137}Cs activities (semi-qualitative analysis) on semiconductor gamma-spectrometer without observation of required geometry. Measurements were carried out on gamma-spectrometer with impulse analyzer Nomad Plus with scintillation detector on the base of alkaline-halogen crystal. The package of Gamma Vision software was used. Based on the obtained data all samples were divided into groups with approximately equal concentrations of artificial radionuclides. The qualitative analysis of artificial radionuclide concentrations in soil samples was made using Canberra gamma-spectrometer. Concentration of Sr was determined on beta-spectrometer "Progress-BG".

2.3. State of technical sites P-1, P-2, P-3, P-5, P2-G and P-7

To study radiation situation and to make an inventory of radiation-hazardous objects detailed examinations were made on technical sites P-1, P-3, P-5, P-2, P2-G and P-7. The first stage included detection of radiation-contaminated areas, making of survey grids with different spacing 200×200, 100×100 and 40×40 meters. Pedestrian gamma-survey including EDR measurements in node points at a height of 0.03 m and measurements in the mode "search" between points were made. The obtained information was used to make EDR maps of the studied area.

The second stage included studying of vertical radionuclide distribution in epicenter zones. It consisted of layerwise soil sampling at different distances from the epicenter. First, a test pit was dug. The profile (test pit) had 60-80 cm in width, 150-200 cm in length and 100-150 cm in depth. To study soil in the adjacent key areas test profiles of lower depth (20-30cm) were made there. Then layerwise soil samples were taken in accordance with the instruction [5].

2.4. Analytical measurements

To estimate the total amount of beta-containing radionuclides, the initial samples were measured with Radiagem 2000 instrument with a block of alpha-/beta-radiation SAB-100 in compliance with the instruction [27].

To register gamma-radiating radionuclides (^{60}Co, ^{137}Cs, $^{152,154,155}Eu$ and ^{241}Am), the soil samples were dried in the drying box at a temperature of 105-110˚C for 6-12 hours or in the racks for sample drying in plastic cuvettes under exhaust hood to air-dry state, periodically mixing them with pallet.

The samples were sifted to remove stones and roots. To sift we used a sieve with 1 mm cells. Large-sized fractions were not measured. The dried sample was grinded in the ball mill or in the mortar and carefully mixed till uniform state. For gamma-spectrometric analysis a portion weighing 500-700 grams was taken [11, 19].

Gamma-spectrometric analysis was made using Canberra gamma-spectrometric facility with a semiconductor detector of gamma radiation GX 2020 with relative efficiency for gamma radiation 20%, a crystal of super-pure germanium, an impulse analyzer Canberra InSpector 1200 and a package of Canberra Genie-2000 3.1 software [20]. Measurements lasted for 2-3 hours depending on the activity of the studied sample. The specific activity of ^{90}Sr was determined on the beta-spectrometric complex Progress, SPO Doza, with scintillation beta-detector and impulse analyzer SKS-99 SPUTNIK. In beta-spectrometric measurements 20 g samples were placed in a special measuring cuvette. The average detecting limits were 1.2 Bq/kg for ^{60}Co, 0.8 Bq/kg for ^{137}Cs, 5 Bq/kg for ^{152}Eu, 6 Bq/kg for $^{154,155}Eu$ and 0.5 Bq/kg for ^{241}Am.

3. RESULTS OF INVESTIGATIONS

3.1. State of the "Experimental field" site

3.1.1. Results of visual inspection

The territory of the "Experimental field" site is a plain of about 20 km in diameter surrounded by low mountains, where 6 technical sites are located. The territory has high level of man-caused disturbance of the landscape in the form of ditches, gutters and trenches, which appeared after closure of the Semipalatinsk Test Site. The highest level of landscape disturbance is observed on the territory of site P-1.

The territory has a diversified network of earth roads: the three main roads pass through the center to northern and southern parts of the "Experimental field" site, and minor roads are, as a rule, directed from equipment buildings to epicenters. Each site has its own structures, which were used as objects of infrastructure in order to determine their hardness characteristics under the action of heat radiation and shock waves. The sites also have crash-proof reinforce structures not looking like infrastructure objects. They are located at different distances from the epicenters of explosions. They were used to place equipment registering different explosion parameters.

An analysis of the satellite image (figure 2) showed high degree of land degradation around the epicenter of technical site P-1. It is probably caused by a large amount of slag formed in the thermonuclear experiment. Each technical site has white-clay crosses for targeted bombing from plane during atmospheric tests. As a rule, crosses are displaced with respect to the centers of the technical sites. On the technical sites one can see contours of craters formed by ground nuclear tests.

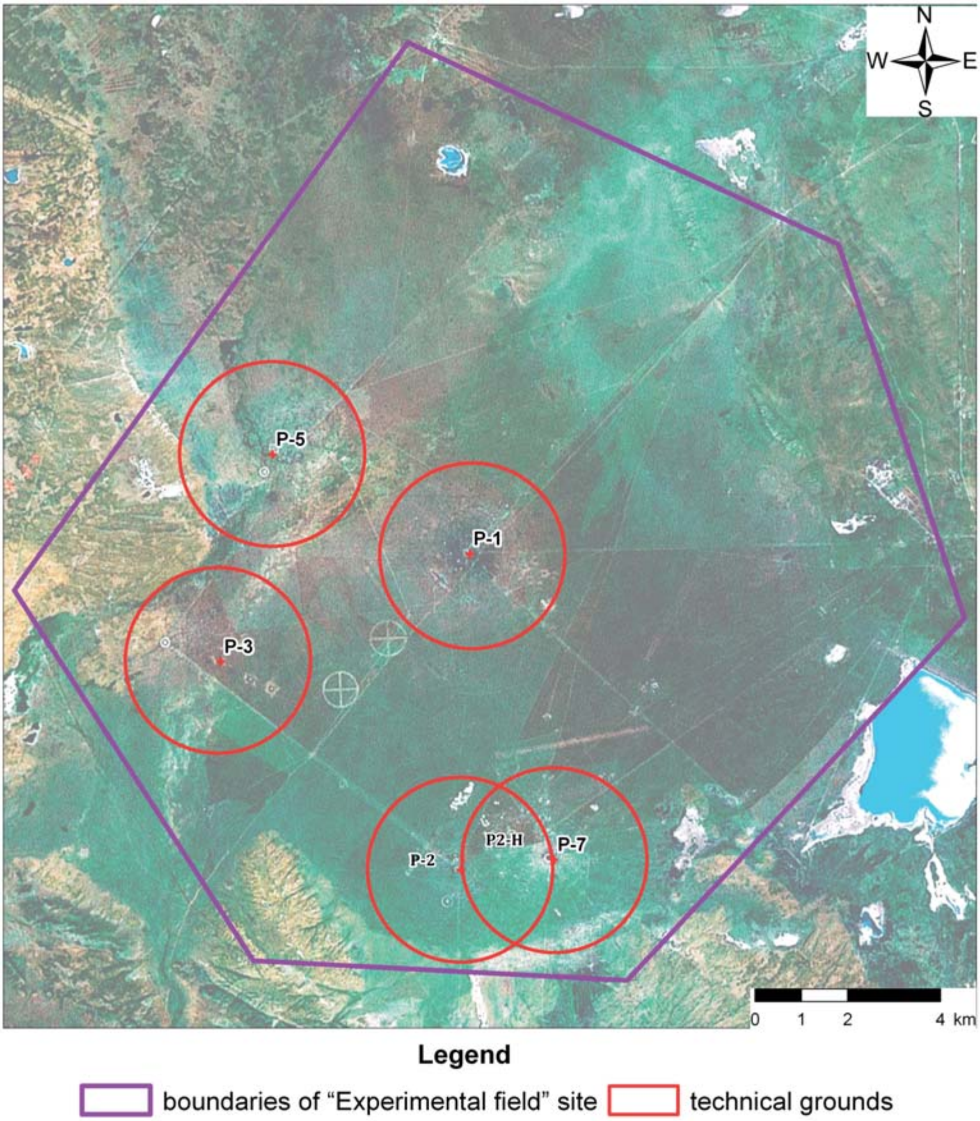


Figure 2. Satellite image of the territory of the "Experimental field" site

3.1.2. Results of investigations of the state of technical sites

On the territory of technical sites P-2, P2-G and P-7 1044 man-made objects were discovered. On the territory of P-3 – 88 objects, and on the territory of P-5 – 24 objects. Maps of their locations on technical sites are shown in figures 3 and 4. Some of them are shown in figure 5. Most of such man-made objects are trenches, concrete underground and ground structures, caponiers, wells, ditchbanks, cavities and hollows. In the vicinity of each object radiation parameters were measured, its coordinates were determined and its photograph was made.

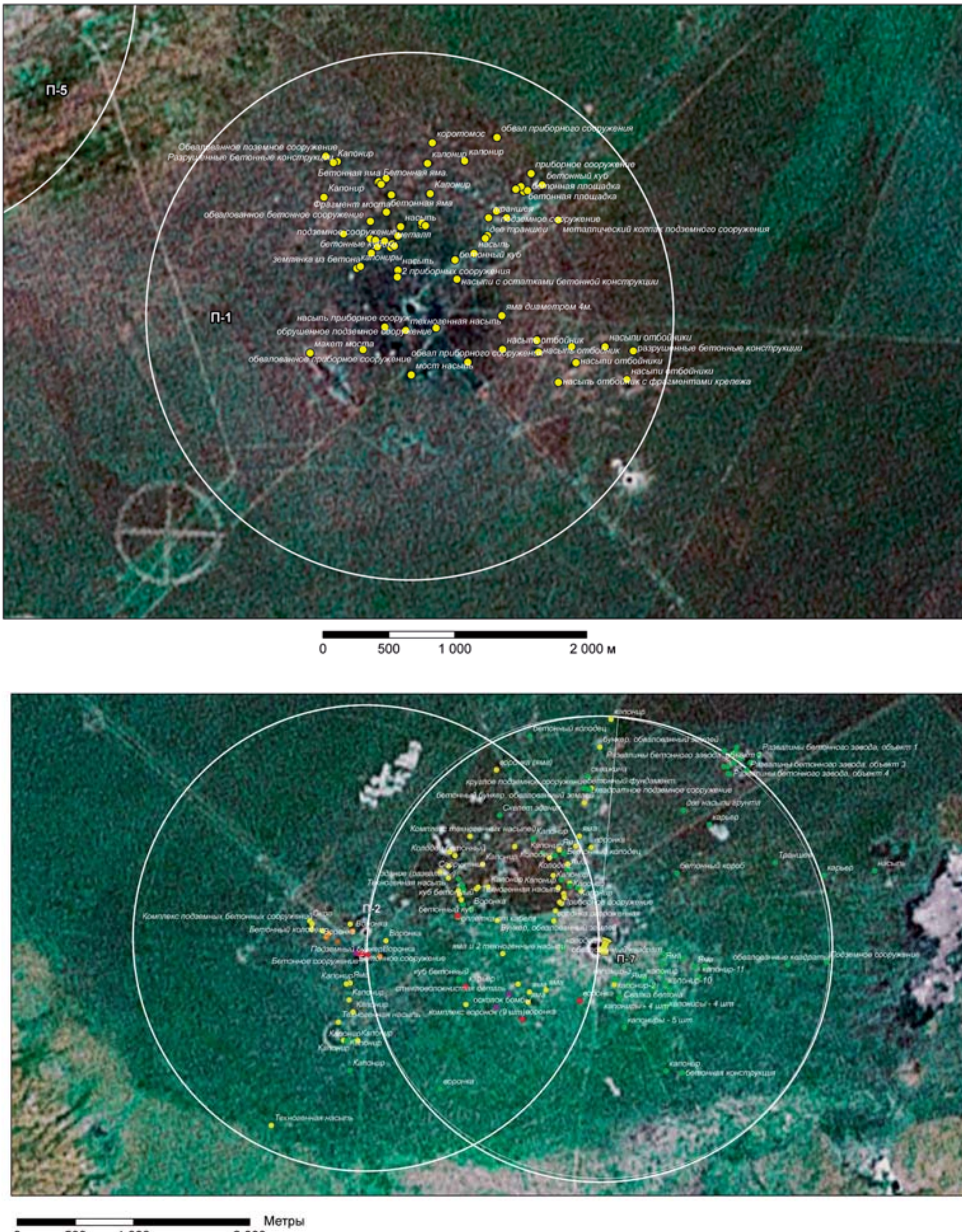


Figure 3. A schematic map showing location of man-made objects on technical sites P-1, P-2, P2-G and P-7.

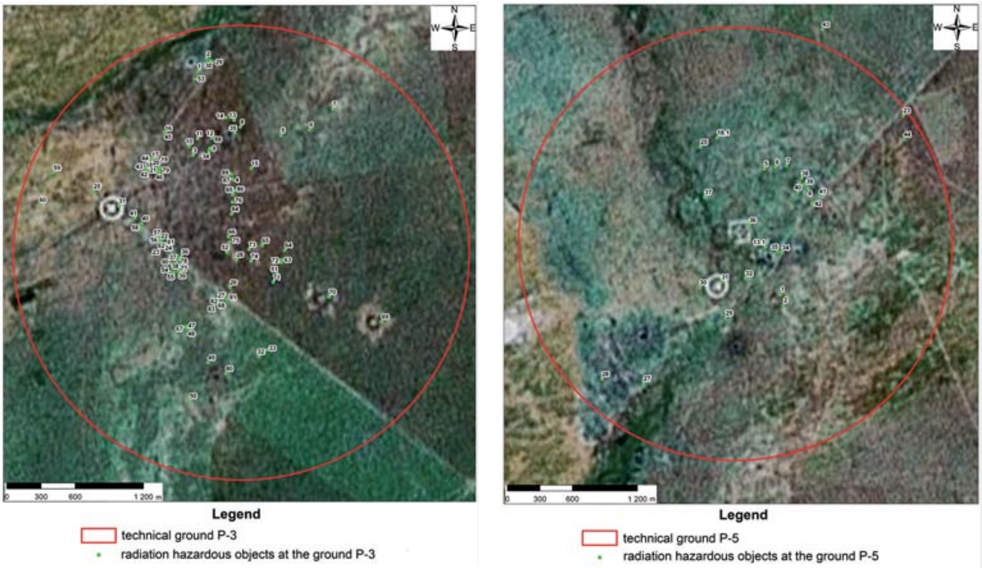
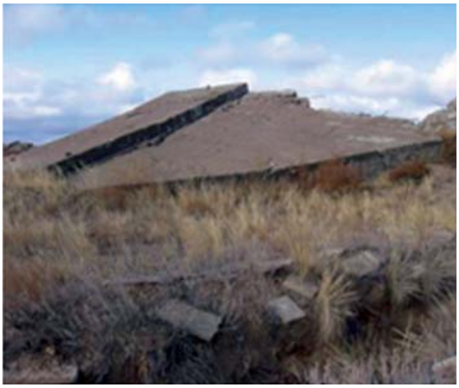


Figure 4. A schematic map showing location of man-made objects on technical sites P-3 and P-5

4-storied concrete structure (gander) where registering devices were placed. Such structures were mounted on 8 borders in two azimuth ranges R = 500-10000 m

A metal structure in the form of a bunker of 1 m in diameter



Heaped-up device structure (gander)

A concrete structure of tunnel type

A wooden construction like a well, depth 5 m

An imitator of tank tower, cemented

An underground bunker

An underground concrete construction with stairs going underground

A model of a silo launching facility of a depth of about 10 m

A wooden bunker in the ditchbank, depth up to 3 m

Figure 5. Some man-made objects discovered as a result of reconnaissance survey

All technical sites, as a rule, have hollows formed as a result of ground explosions. Most of them are filled with ground waters. The areas of oil piling and nearby territory are covered by fused rocks forming so called "slag fields" usually covering areas forming a circle of a radius of 100 meters around epicenters (figure 6). There are also craters with radiation parameters not exceeding background parameters, which can be explained by chemical-type explosions.

Figure 6. Fused soil in the vicinity of the epicenter

3.1.4. Radiological situation on the territory of the "Experimental field" site

3.1.4.1. General assessment by integral radiation parameters

The results of pedestrian gamma- and beta-survey were used to obtain EDR distributions (figure 7) and distributions of areal activity of beta-emitting radionuclides (figure 8).

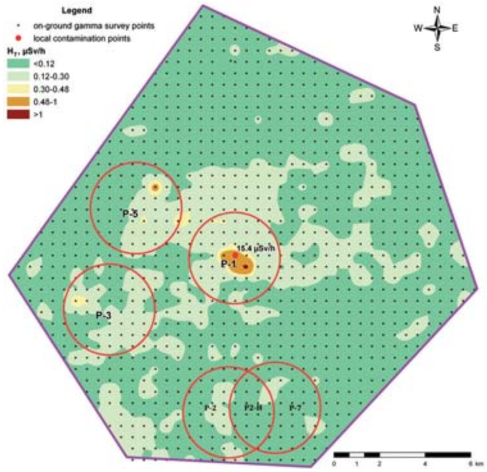


Figure 7. A map of EDR distribution on the "Experimental field" site

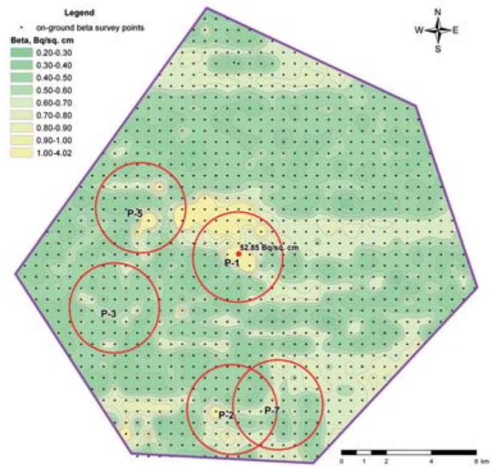


Figure 8. A map of contamination of the "Experimental field" site with β-emitting radionuclides

The EDR level varies from 0.10 to 16 µSv/h with background level on the test site equal to 0.10-0.12 µSv/h. The density of beta-radiation varies from <10 to 5500 (part/cm^2×min). More precise data for EDR level and beta-radiation density can be obtained by using a smaller-meshed net in the epicenter zones, which gives more precise results on the contaminated area.

Therefore, we can state that the territory of the "Experimental field" does not have uniform contamination; it may have "clean" areas. The integral radiation parameters show that only a small part of the "Experimental field" can be classified as radiation-contaminated area.

To determine the degree of potential hazard of the site in terms of external irradiation we will make a rough estimation of the maximal permissible EDR level for population on the site. According to NRB-99 [28] the dose limit for population from artificial sources is 1 mSv/year = 1000 µSv/(365 x24)hours ~ 0.12 µSv/h. Neglecting internal irradiation from artificial radionuclides and summing up the background level and maximal permissible irradiation dose from artificial sources, we can estimate the EDR level at which it is necessary to limit the time of people staying on the "Experimental field". This value is 0.24 µSv/h. Using the EDR map we estimated the area with EDR level exceeding 0.24 µSv/h, it was equal to 11 km^2, i.e. 3.6% of the total area of the "Experimental field". Staying of local people on this area must be limited.

Maximal values of radiation parameters (probably, superposition of radioactive fallouts traces) were registered on the territory of technical sites P-1, P-5 and on the area between them. Signs of long traces of radioactive fallouts of radionuclides – beta-emitters are also observed in northern, southeastern and southern parts.

3.1.3. Character of contamination of the "Experimental field" site with artificial radionuclides

Based on the data of quantitative analysis of soil samples taken on the test site, maps and diagrams of areal distribution of artificial radionuclides concentrations on the "Experimental field" site were made (figure 10).

The diagrams were based on the laboratory data on specific activities of artificial radionuclides and to make them more demonstrative the logarithm scale was used. In case specific activity of a radionuclide was below the detection limit for the radionuclide, the detection limits were used as numerical values. The scheme of location of profiles and their numbers are shown in the figure (figure 9).

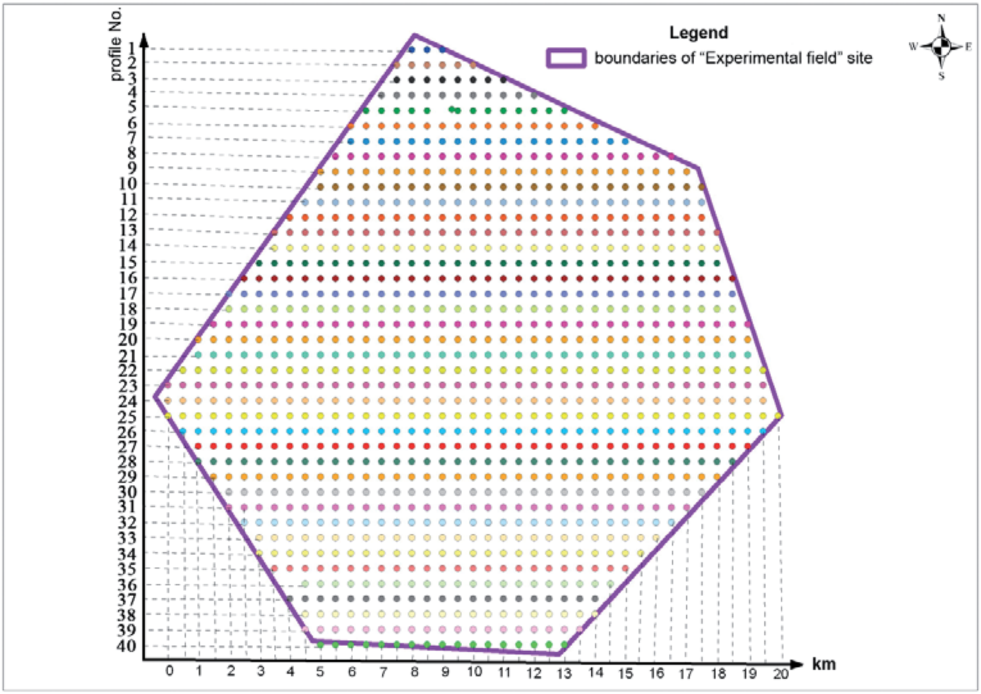
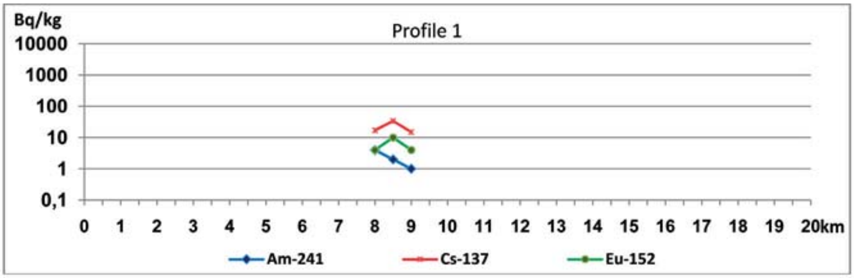


Figure 9. Location of profiles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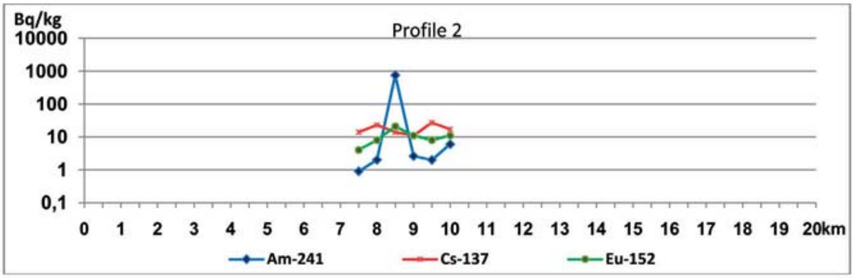
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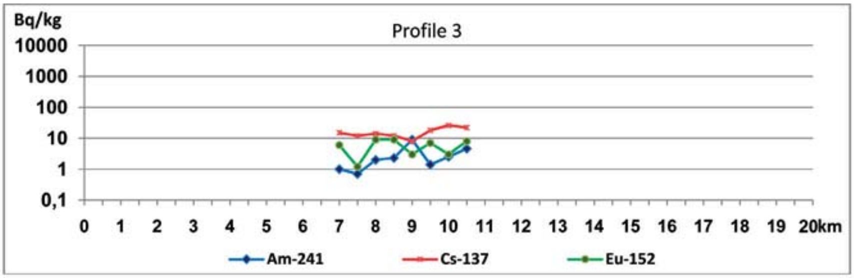
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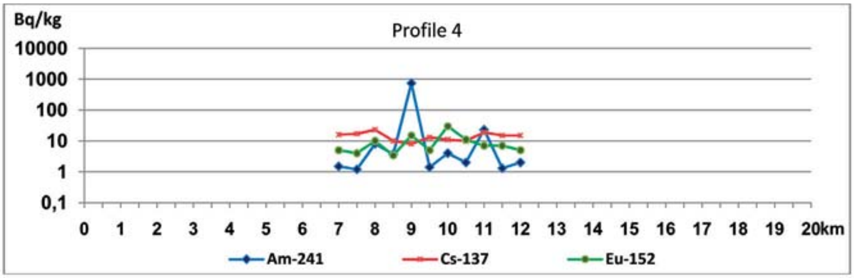
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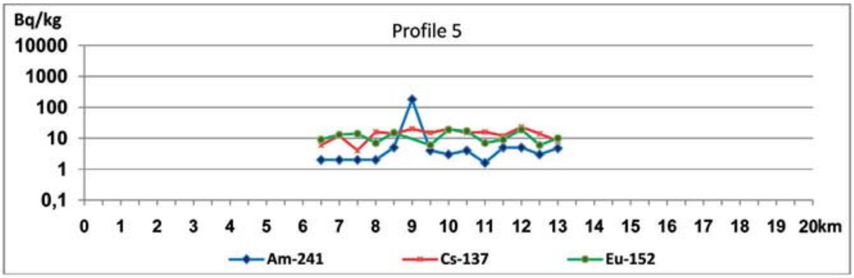
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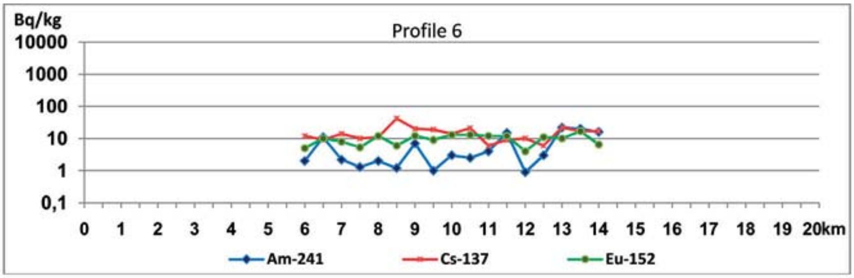
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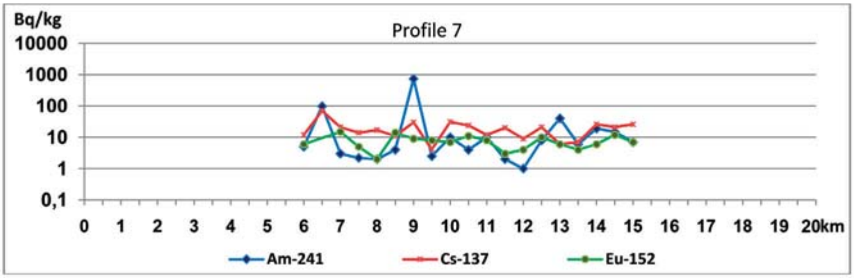
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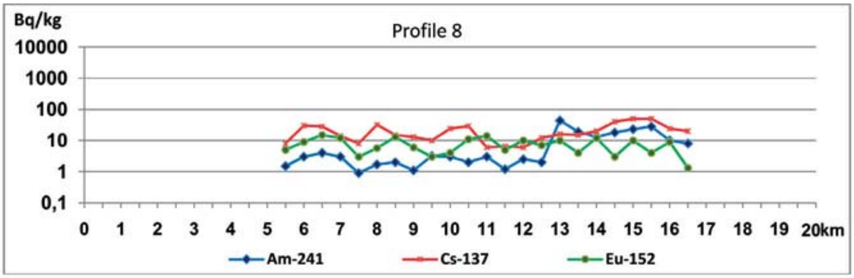
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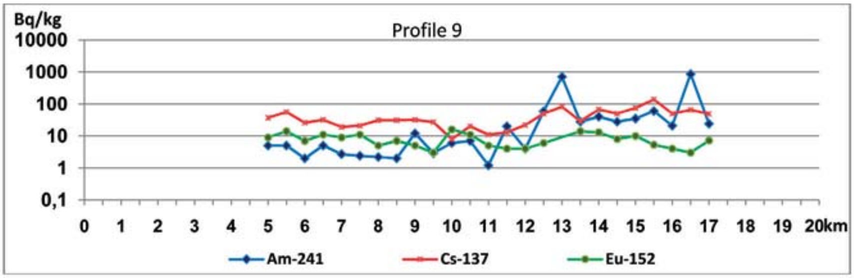
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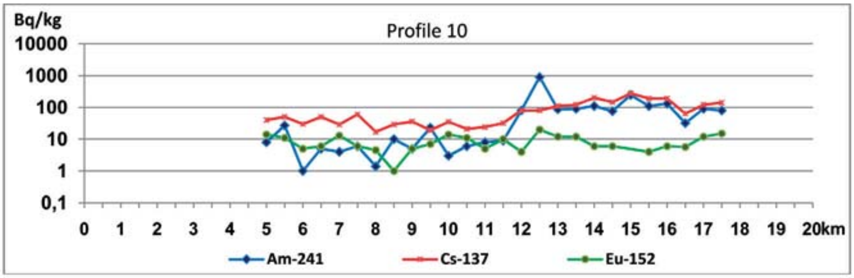
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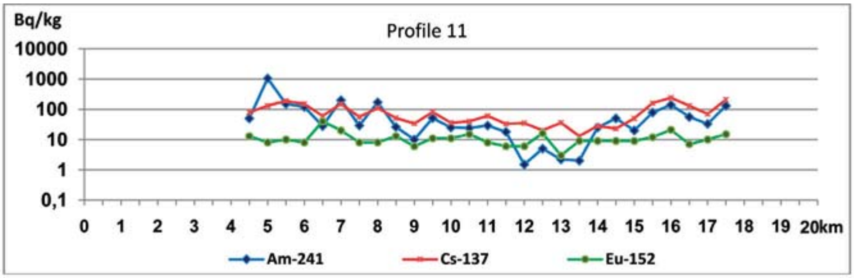
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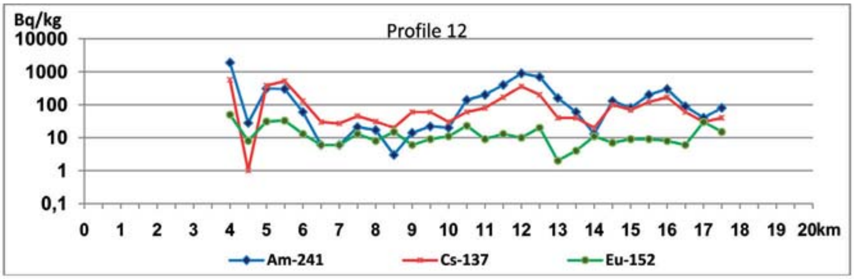
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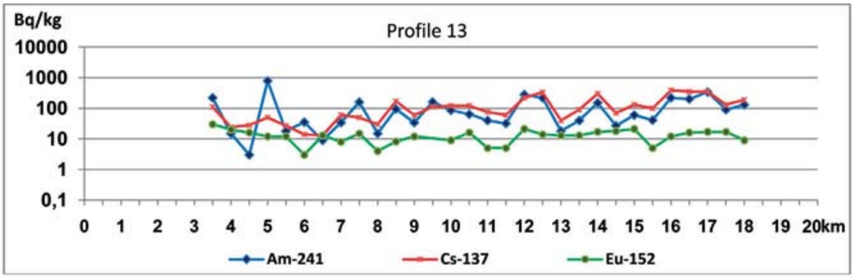
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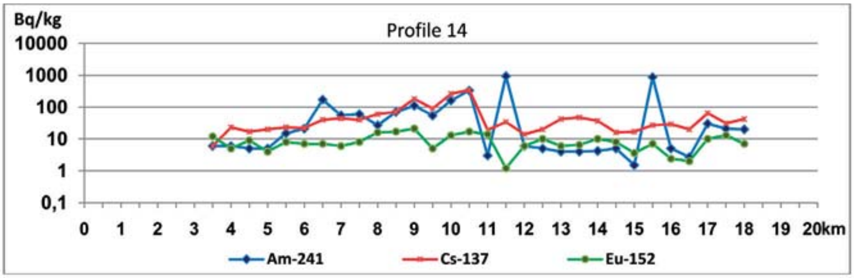
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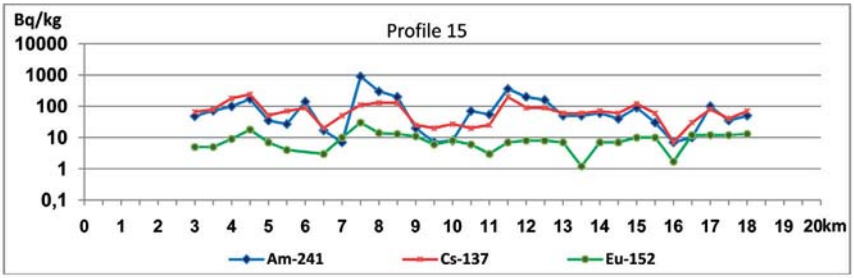
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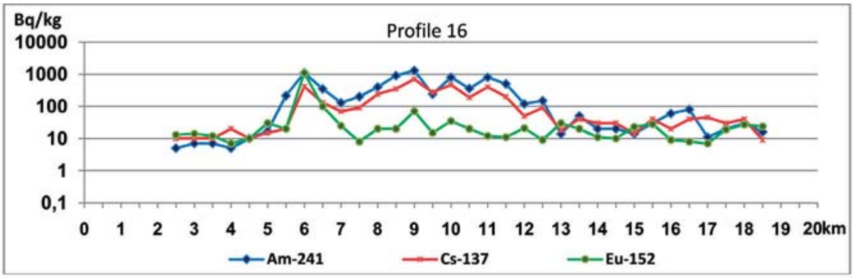
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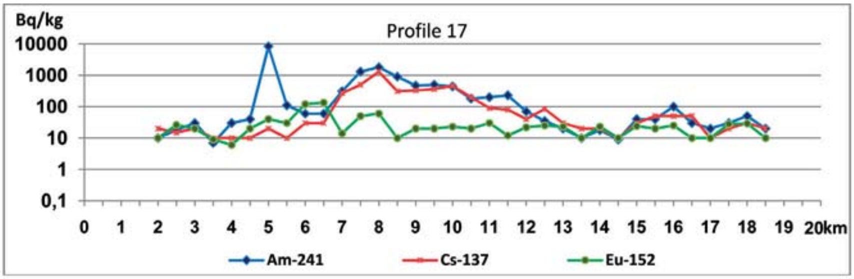
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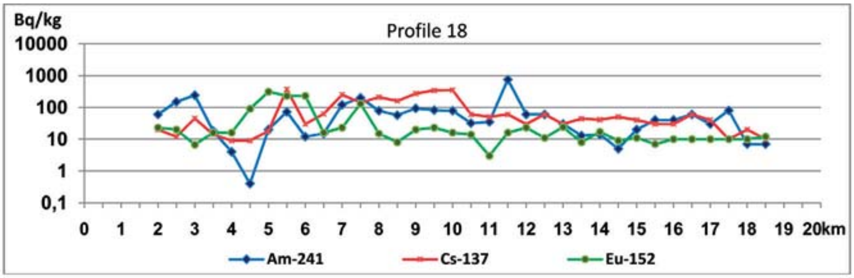
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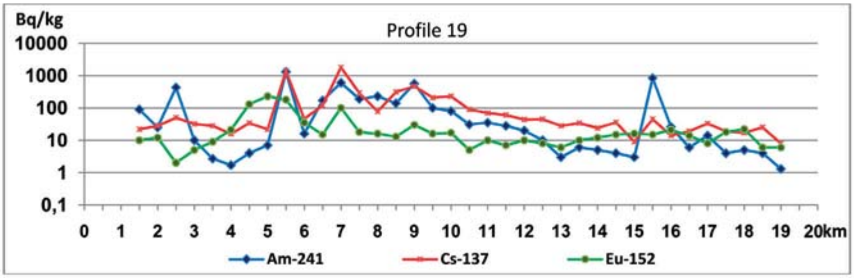
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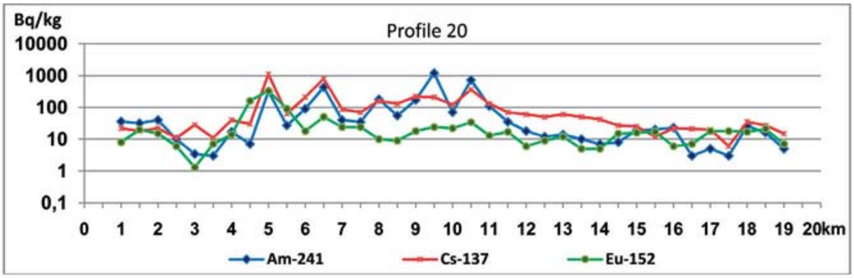
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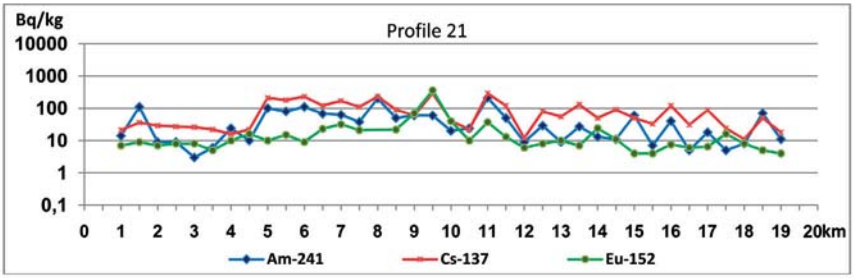
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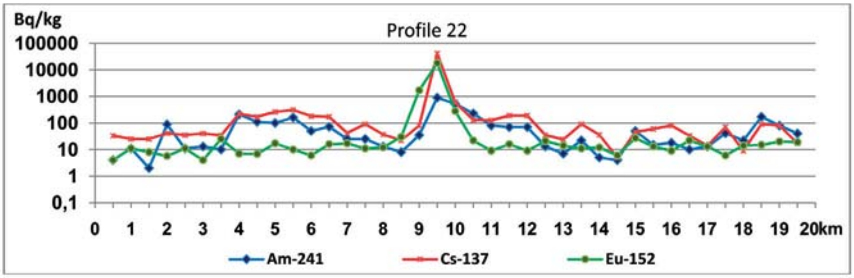
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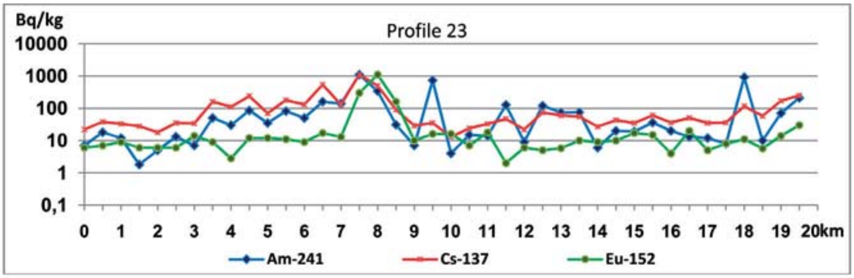
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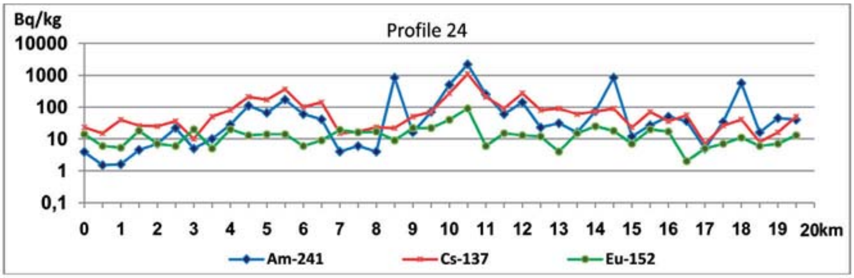
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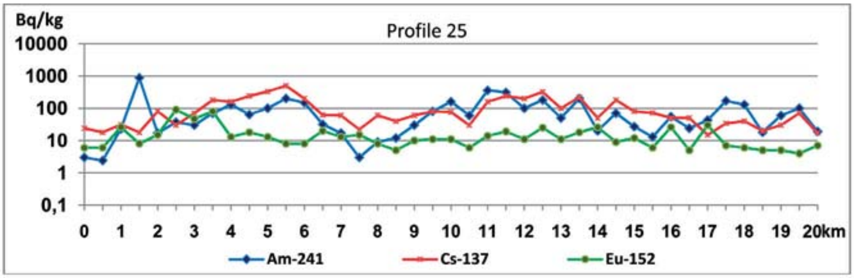
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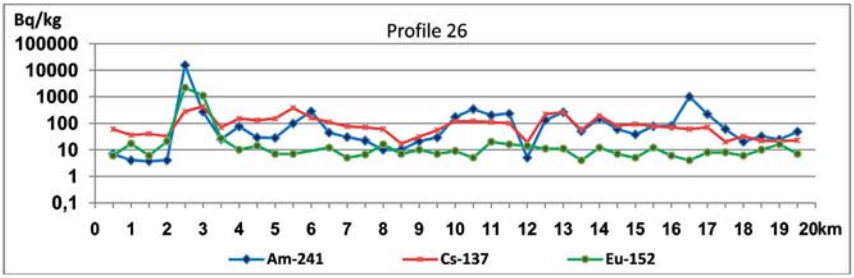
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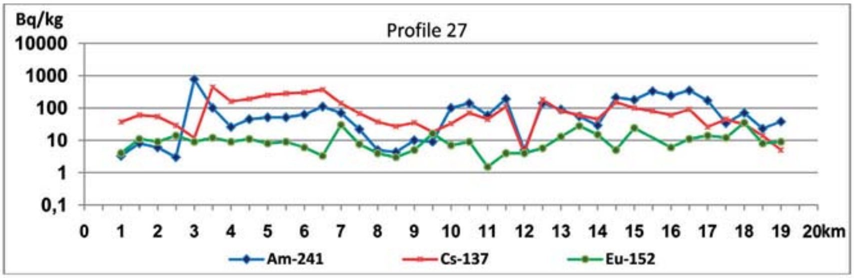
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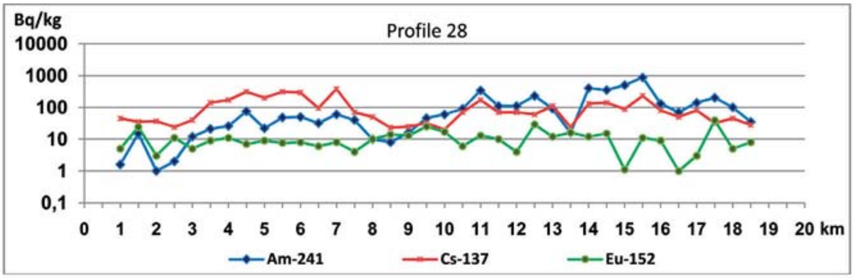
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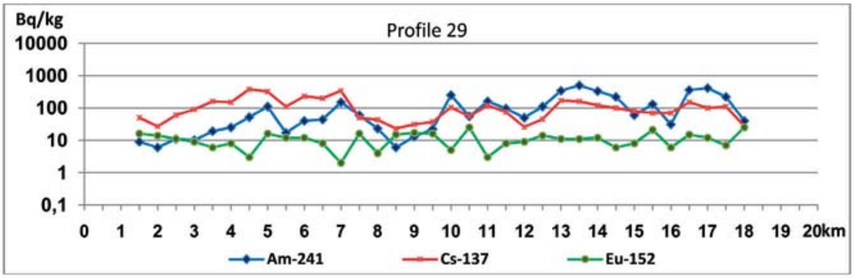
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 km
Am-241
Cs-137
Eu-152


Bq/kg
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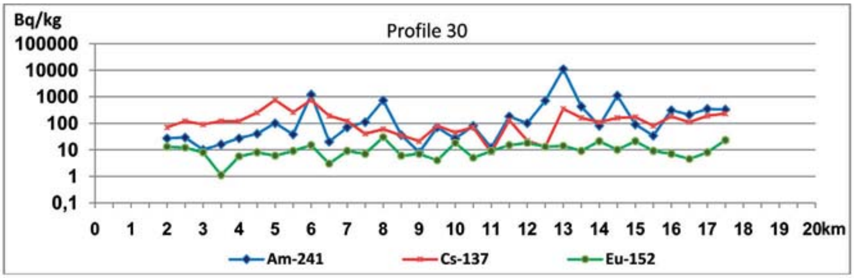
Am-241
Cs-137
Eu-152


Bq/kg
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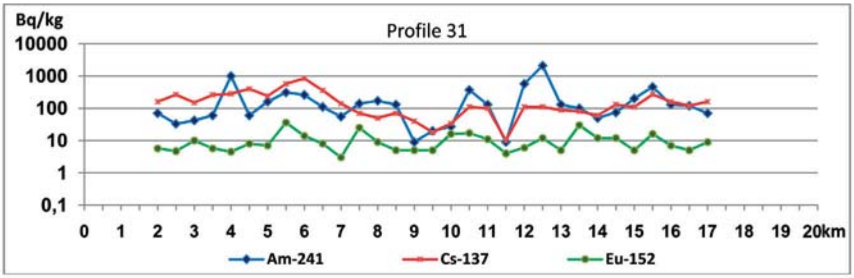
Am-241
Cs-137
Eu-152


Bq/kg
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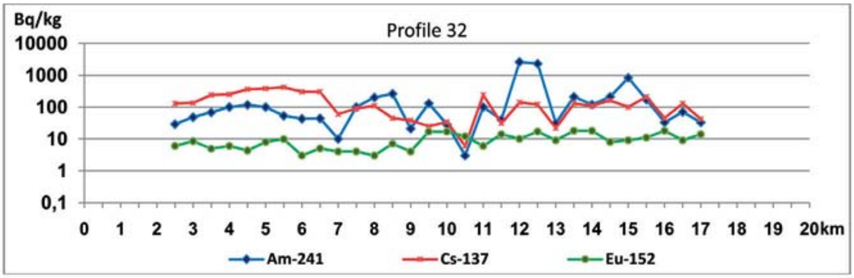
Am-241
Cs-137
Eu-152


Bq/kg
Profile 32
10000
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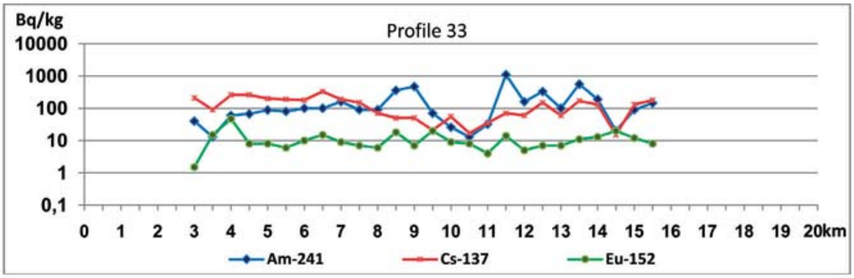
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20km
Am-241
Cs-137
Eu-152


Bq/kg
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10000
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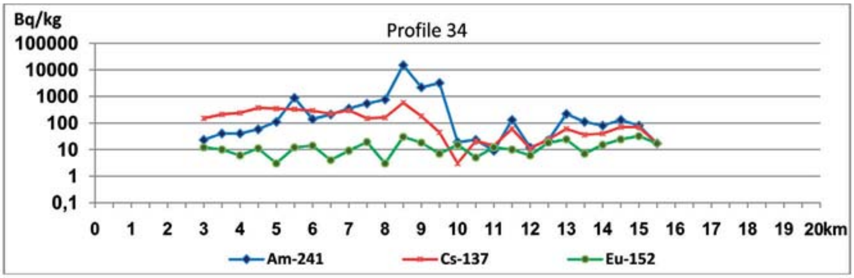
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20km
Am-241
Cs-137
Eu-152


Bq/kg
Profile 34
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10000
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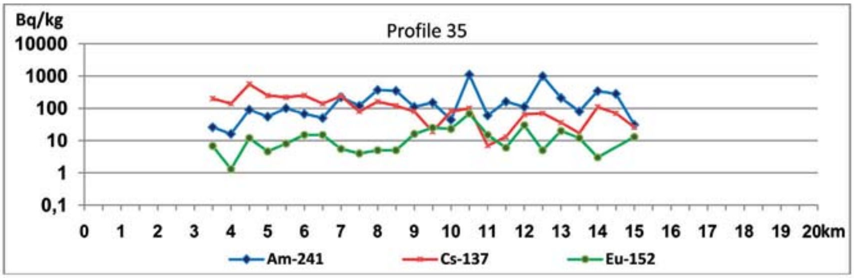
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20km
Am-241
Cs-137
Eu-152


Bq/kg
Profile 35
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0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20km
Am-241
Cs-137
Eu-152

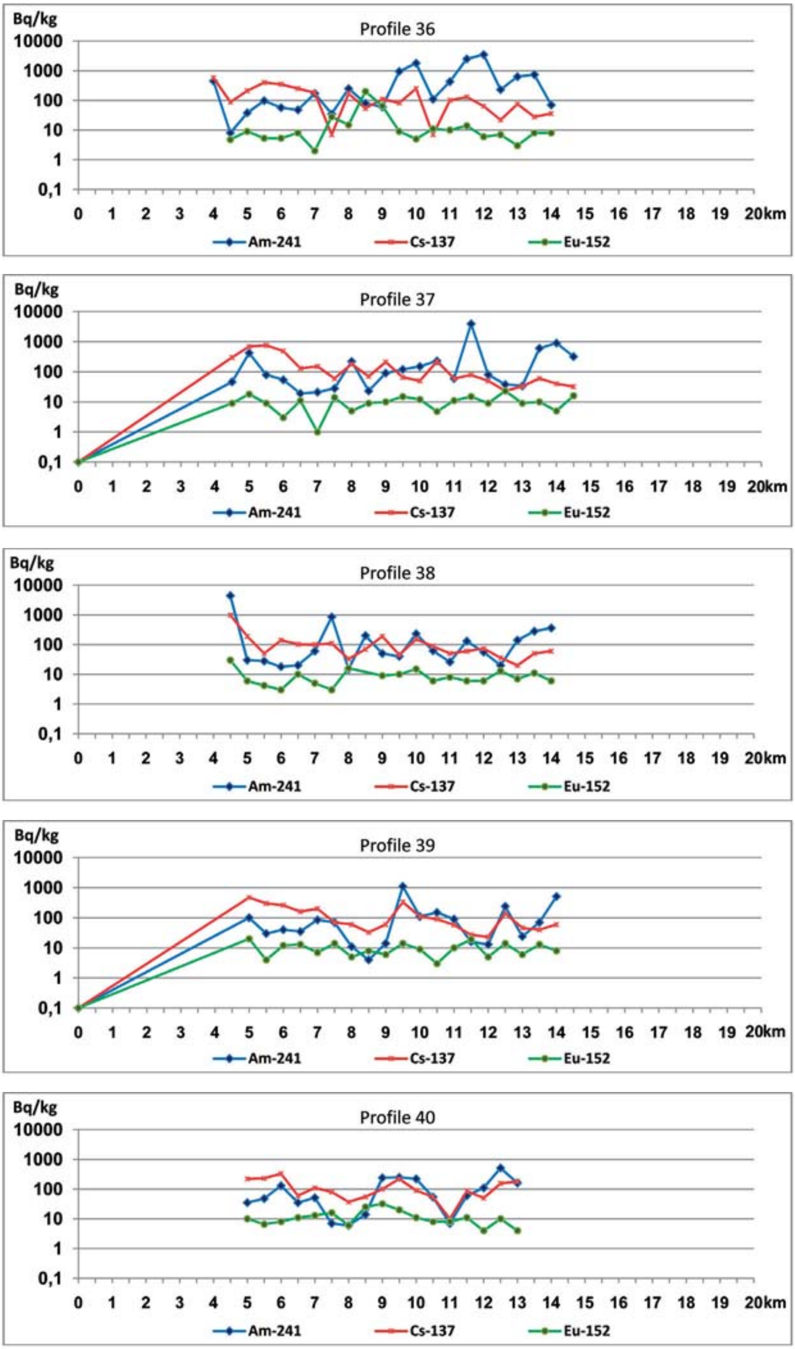


Figure 10. Distribution of radionuclide concentrations on the "Experimental field" site

The above figures enable to make a conclusion that on the "Experimental field" there are relatively clean areas, for example, in northern part to the north from profile No.7, in eastern and western parts. ^{241}Am and ^{137}Cs concentrations in the areas are comparable with the level of global fallouts, ^{152}Eu and ^{60}Co are not detected. At the same time, the above territories have spots with high ^{241}Am concentrations up to n×10^{3} Bq/kg with ^{137}Cs concentrations at the level of global fallouts, which can, most probably, be explained by fallouts due to hydrodynamic or hydronuclear explosions.

An analysis of the character of artificial radionuclides distribution enables to identify two types of contamination: "point" and areal contamination, where point areas can be subdivided into two categories. One group of points is characterized by high ^{241}Am concentrations at rather low concentrations of radionuclides – decay products and activation levels, the other group has high concentrations of artificial radionuclides. "Point" spots of type 1 are probably caused by fallouts from hydrodynamic or hydronuclear explosions. "Point" spots of type 2 can be identified as epicenters of nuclear explosions.

Spots of areal contamination are located beyond the territories of technical sites, they have high concentrations of ^{241}Am and ^{137}Cs, with the ratio of isotopes varying from place to place. It is likely that such spots appeared as a result of superposition of fallouts from explosions of different types. In some cases such areas spread beyond the "Experimental field".

The products of neutron activation, ^{60}Co and ^{152,154}Eu, are mainly concentrated directly in the epicenters of experiments. High concentration of activation products in soil is an identifier of close location of explosion epicenter. In profiles Nos.16, 18, 19, 20, 21, 22, 23, 26 and 36 peaks of increase in ^{152}Eu concentration, which identify about 6 epicenters, were registered. One of such places was discovered in profile No.16 (northern part of technical site P-5).

In southern part of the "Experimental field" the main contaminant is ^{241}Am. Large areas with concentrations more than n×10^{3} Bq/kg were detected. Taking into account that ratio $^{239+240}$Pu/^{241}Am varies from 5 to 20, such areas must have high concentrations of $^{239+240}$Pu.

The maps (figures 11-12) show areal distribution of artificial radionuclides ^{137}Cs and ^{90}Sr. To compare the obtained data, all available data including the results of ISTC project K-337 were presented in the figures.

To estimate the factors that influenced formation of the character of contamination by fission products, the average wind directions during tests were superimposed on the map of ^{137}Cs distribution. The obtained data on ^{137}Cs and ^{90}Sr areal distributions on the territory of the ground "Experimental field" enable to determine the main traces of radioactive fallouts of fission products. The contamination formed three areas elongated in northeastern, southeastern and southwestern directions; the areas are shown by a dotted line (figure 11). The traces were probably formed as a result of superposition of many traces of radioactive fallouts and have very large areas. It can be stated with high degree of certainty that they spread beyond the administrative boundaries of the "Experimental field". Taking into account directions of traces one can suppose that the northeastern trace was formed by fallouts from explosions 11.11.62 and 07.05.62, the southeastern trace was formed by fallouts from explosions 12.08.53, 24.08.56, 05.08.55, 18.09.61, 09.09.61, 29.07.55, 14.09.61, 24.12.62, 26.11.62 and the southwestern trace is a result of explosions 05.10.54, 25.03.56 and 24.09.51. To estimate the degree of radioactive contamination of lands we used the parameter of minimal-significant specific activity (MSSA) and criteria of territory classification as zones with different degree of ecological disturbance (table 4).

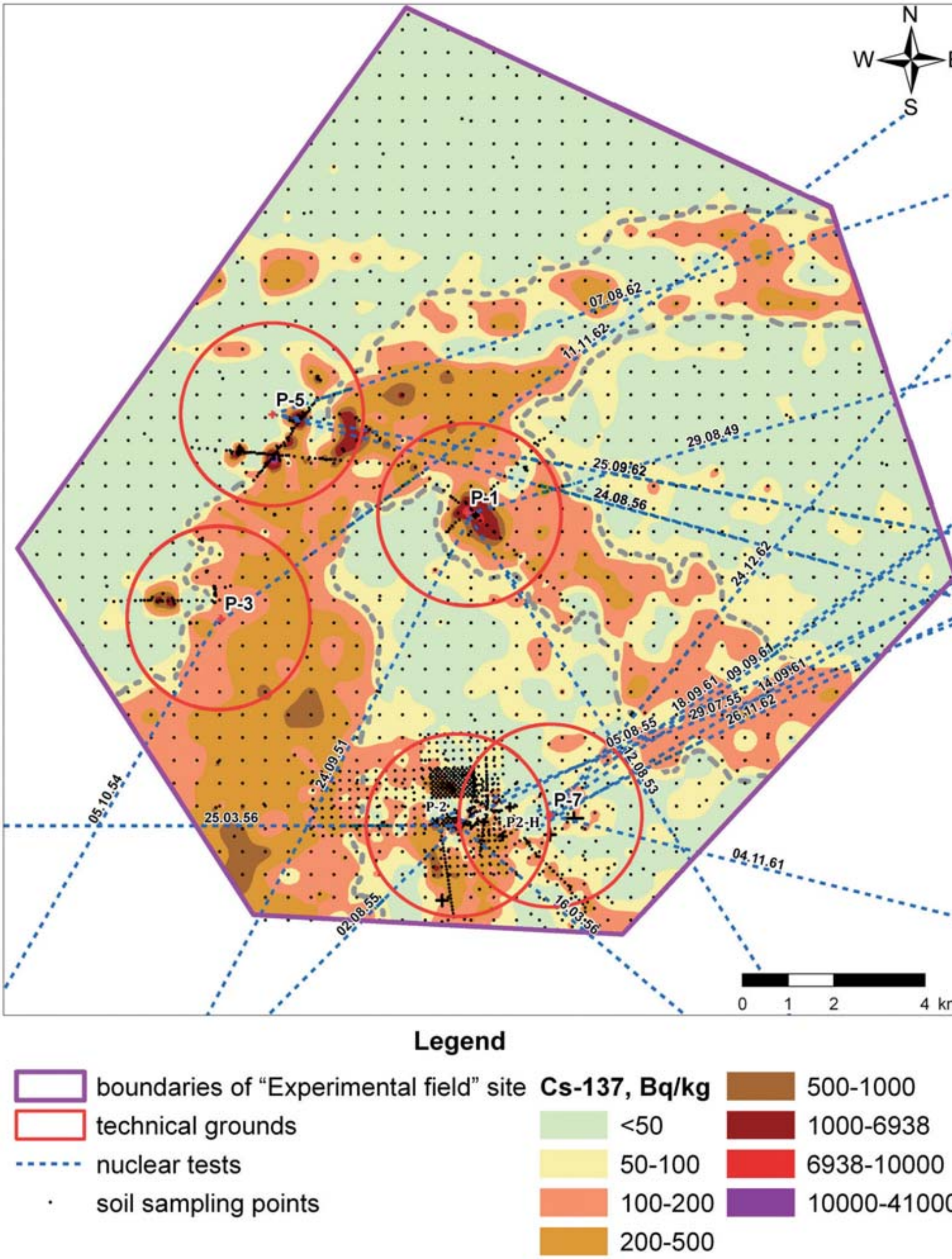


Figure 11. A map of ^{137}Cs distribution on the territory of the "Experimental field"

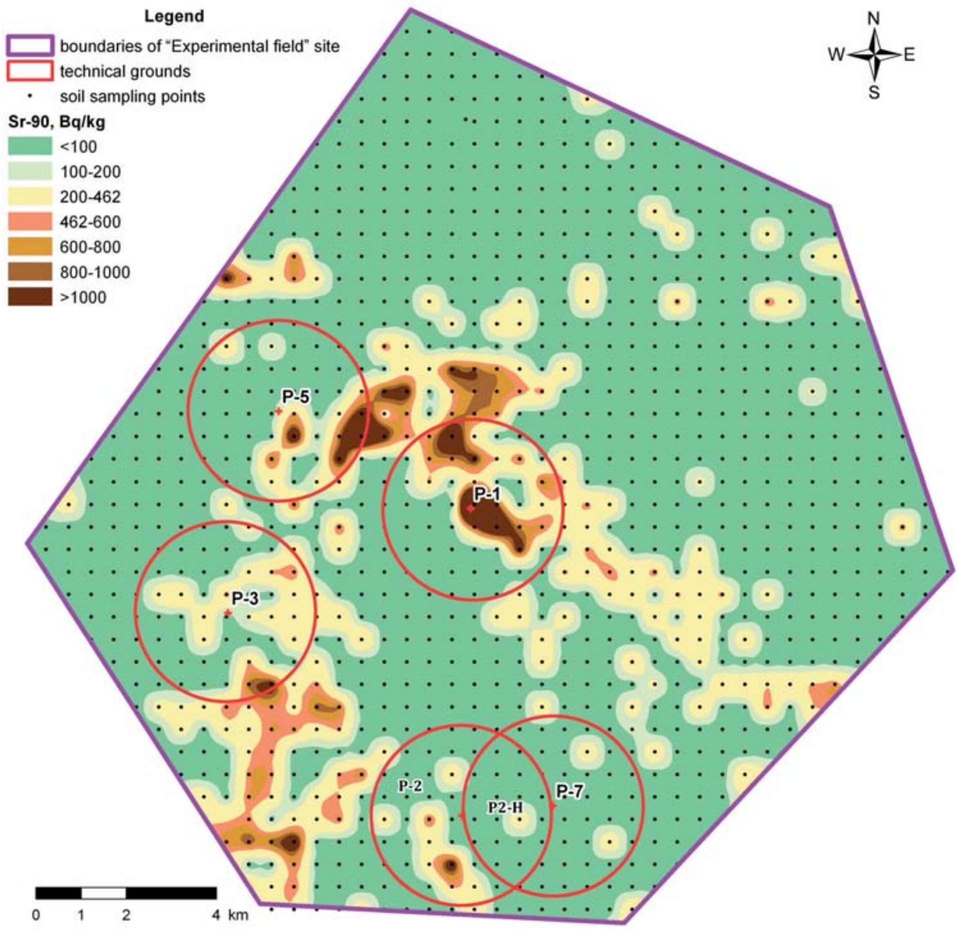


Figure 12. A map of ^{90}Sr distribution on the territory of the "Experimental field"

Table 4.

Indicators for radioactive contamination of soils [1]

Indicator	**Parameter**		
	Ecological disaster	**Emergency ecological situation**	**Relatively satisfactory situation**
	Radioactive contamination, Bq/kg*		
^{137}Cs	More than 18500	6938 – 18500	Less than 6938
^{90}Sr	More than 1388	462 – 1388	Less than 462
$^{239+240}Pu$, ^{238}Pu	More than 46.3	23.1 – 46.3	Less than 23.1
Note: * specific activity was calculated for 5cm soil layer and 1.6 kg/dm^3 soil density			

Based on the data (table 4) one can estimate areas of territories on the "Experimental field" site that must be referred to different types of zones according to the criteria of ^{137}Cs and ^{90}Sr contamination. The results are given in the table (table 5).

Table 5.

Assessment of the degree of contamination of the "Experimental field" with fission products

Radionuclide	Specific activity, Bq/kgr	RAW area	Area of ecological disaster	Area of emergency ecological situation	Area of relatively satisfactory situation
^{137}Cs	<1 to 41,000	about 1 km^2	1 km^2	about 3 km^2	about 296 km^2
^{90}Sr	<100 to 140,000	about 0.3 km^2	3 km^2	about 6 km^{2c}	about 291 km^2

Therefore, in terms of contamination with fission products almost all territory of the "Experimental field" can be classified as territory with relatively satisfactory ecological situation.

The figures (figure 13*,* figure 14) show maps of distribution of neutron activation products, ^{152}Eu and ^{60}Co, on the territory of the "Experimental field".

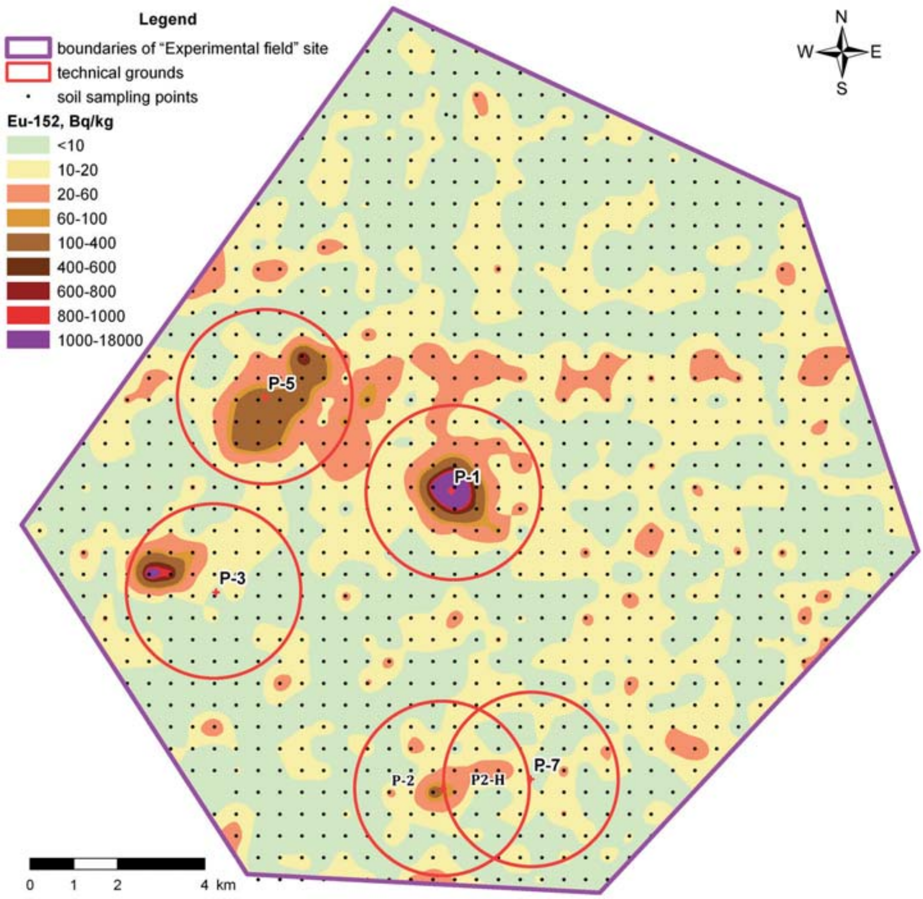


Figure 13. A map of ^{152}Eu distribution on the territory of "Experimental field"

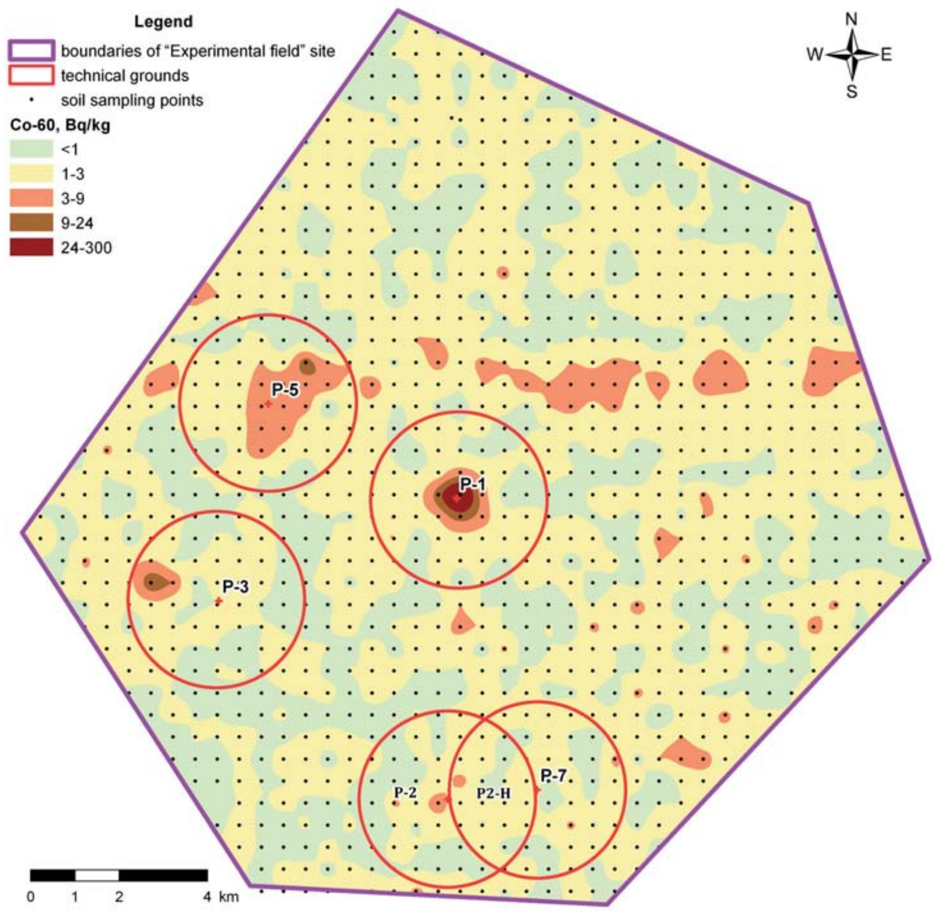


Figure 14. A map of ^{60}Co distribution on the territory of "Experimental field"

As the distance to the test epicenter decreases, the specific activity of ^{152}Eu increases from <4 to 18,000 Bq/kg, ^{60}Co specific activity increases from <1 to 300 Bq/kg, the ratio $^{152}Eu/^{60}Co$ varies from 25 to 100. The products of neutron activation, ^{60}Co and $^{152,154}Eu$, are mainly concentrated directly in the epicenters of experiments. However, it should be noted that rather high concentrations of ^{152}Eu were registered near sites P-5, P-1 and near northwestern boundary of the "Experimental field" site (figure 13, countered by a dotted line). They could probably appear as a result of displacement of activated soil (when the crater was formed) by shock wave from test epicenters in the direction of air flows. The highest level of contamination was registered on sites P-1, P-5 and P-3, where high-capacity ground and atmospheric tests were made. Insignificant concentrations were detected on areas located to the east from site P-5 in the form of an elongated trace of radioactive fallouts. A low level of contamination was registered on technical site P-2, and no contamination caused by ^{152}Eu was detected on site P-7. It may be caused by the usage of a large net whose points did not register epicenter zones of experiments.

The figure (figure 15) shows a map of ^{241}Am areal distribution. To construct the map we used all available data for the territory including the results of ISTC project K-337.

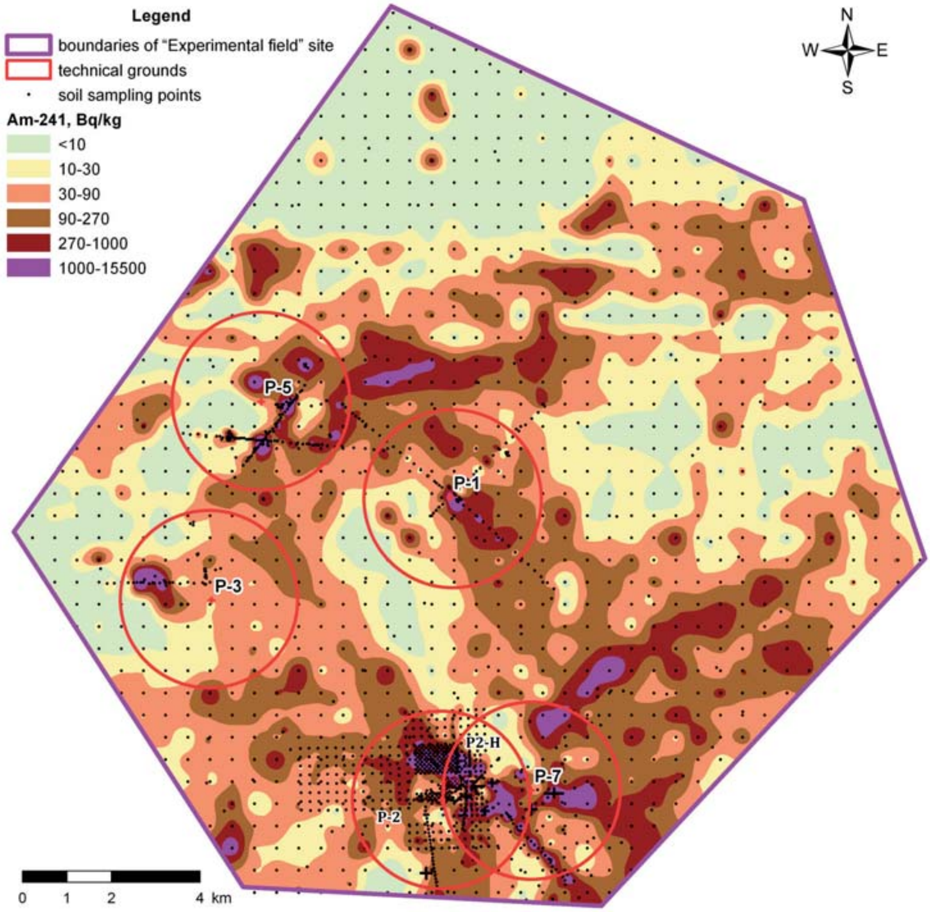


Figure 15. A map of ^{241}Am areal distribution on the territory of the "Experimental field" site

The results obtained enable to make a conclusion that, as a whole, the levels and areas of ^{241}Am contamination have much larger scale than contamination with fission products and activation. ^{241}Am concentration varies from <0.5 to 15,500 Bq/kg. The map of ^{241}Am distribution on the territory of the "Experimental field" site is very helpful in terms of detection of radiation-hazardous objects and planning of their further inventory. The level of contamination with fissile materials is very high. This type of contamination dominates on the territory of the "Experimental field" site.

High ^{241}Am concentration indicates high contamination of the "Experimental field" by the initial component of nuclear charges – $^{239+240}$Pu. In many earlier unexamined areas the ^{241}Am specific activity was over 100 Bq/kg, which can indicate that the level of specific activity of $^{239+240}$Pu>1,000 Bq/kg (taking into account that the average ratio $^{239+240}$Pu/^{241}Am is about 10). It means that newly discovered radiation-hazardous spots have large areas, which may be as high as several tens of square kilometers.

Based on the data of table 4 we estimated areas of the "Experimental field" which refer to zones with different degree of radiation intensity and volumes of radioactive wastes. In calculations the average coefficient of $^{239+240}Pu/^{241}Am$ ratio was taken equal to 10. The results are presented in table 6 below.

Table 6.

Estimation of contamination rates at the "Experimental field" site for fissile materials

Radionuclide	Specific activity, Bq/kg	RAW area, km^2	RAW volume, m^3	Area of ecological disaster, km^2	Area of emergency ecological situation, km^2	Area of relatively satisfactory situation, km^2
$^{239+240}Pu$, ^{238}Pu	from <5 to 150,500	about 40	$\approx 2\times10^6$	about 80	about 120	about 100

According to the data presented in the table, only about 1/3 of the "Experimental field" territory can be classified as lands with relatively satisfactory ecological situation. The average wind directions during tests superimposed on the map, to a large extent, correspond to location of spots with maximal level of ^{241}Am contamination. Radionuclide contamination in the form of 5-6 radiation-contaminated spots spreads beyond the "Experimental field" boundaries. According to the available data one can make a conclusion that priority areas for further investigations are southeastern and southern zones beyond the "Experimental field". As the zones were traces of radioactive fallouts, one can suppose that in those zones the ratio of artificial radionuclides must be more uniform and they must have better correlation $^{239+240}Pu/^{241}Am$ than the areas located in immediate vicinity of the explosion epicenters. In planning further investigations aimed at getting an integral picture of radionuclide contamination of the test site it is, therefore, necessary to carry out additional examination at a distance of 3-6 km off its administrative boundaries. In this investigation the main detected radionuclide must be ^{241}Am and, hence, $^{239+240}Pu$. The four "point" radiation-contaminated spots detected in northern part of the "Experimental field", in the area 350° ÷ 5°, must be verified as, according to the available literature data, no radioactive fallouts were registered there. It should be noted that in the vicinity of *Zhaksytuz* lake (southeastern boundary of the "Experimental field", to the right from P-7), where salt for industrial purposes is mined, an elevated ^{241}Am concentration exceeding 300 Bq/kg was registered.

3.2. Investigations at the technical site P-1

3.2.2. Radiological situation at the territory of the technical site P-1

The technical site P-1 located in the center of the "Experimental field" is a plain of almost the same height. It was the first technical site of the "Experimental field". It is the site where on 29 August 1949 the first Soviet nuclear bomb was tested, and on 12 August 1953 the first thermonuclear charge of capacity of 400 kilotons in TNT equivalent was exploded, 74% of the power of all ground nuclear tests made on the STS were exploded there. As a result of the last test a large crater was formed, and the territory was highly contaminated

[7]. Some witnesses state that reclamation activities including liquidation of man-caused disturbance of natural landscape and site preparation for further activities were carried out. The characteristics of tests on the technical site P-1 are presented in table 1. The view of the epicenter is shown in figure 16.

Figure 16. The epicenter of tests on technical site P-1

To study radiological situation and to make an inventory of radiation-hazardous objects on the technical site P-1 a pedestrian gamma-survey with increased number of readings in the direction towards the site center was made. The results of pedestrian gamma-survey were used to make a map of EDR distribution on the technical site (figure 17).

According to the character of EDR distribution on the technical site P-1, one radiation-hazardous spot with EDR values reaching and exceeding 20 μSv/h was identified. The epicenter zone has an area of about 1 km^2. The center of the contaminated spot has a small crater.

The crater of the radiation-hazardous object (RHO) is small, it does not have a crest (heap), and the difference in heights on its area is insignificant. In the center of the crater is an outlet for outflow of ground waters. The contaminated area with EDR level higher than 0.24 μSv/h, where staying of people must be limited, is about 6 km^2, which makes 48% of the total area of the technical sight. On the map one can see elongated spots of a width up to 100m showing changes in the radiation background. It is supposed that they could appear as a result of reclamation in the epicenter zone. In order to visualize EDR distribution on the site, a three-dimensional map of contamination distribution was made (figure 18).

Figure 19 shows maps of areal distribution of artificial radionuclides ^{137}Cs and ^{241}Am on the territory of the technical site P-1.

The results of areal ^{241}Am distribution on the territory of the technical site P-1 enable to identify two radiation-hazardous zones, which can be classified as radiation-hazardous objects. Their origin can be caused not only by tests on the technical site P-1 but also by tests on other sites, for example, it refers to the contaminated area in northern part of site P-1.

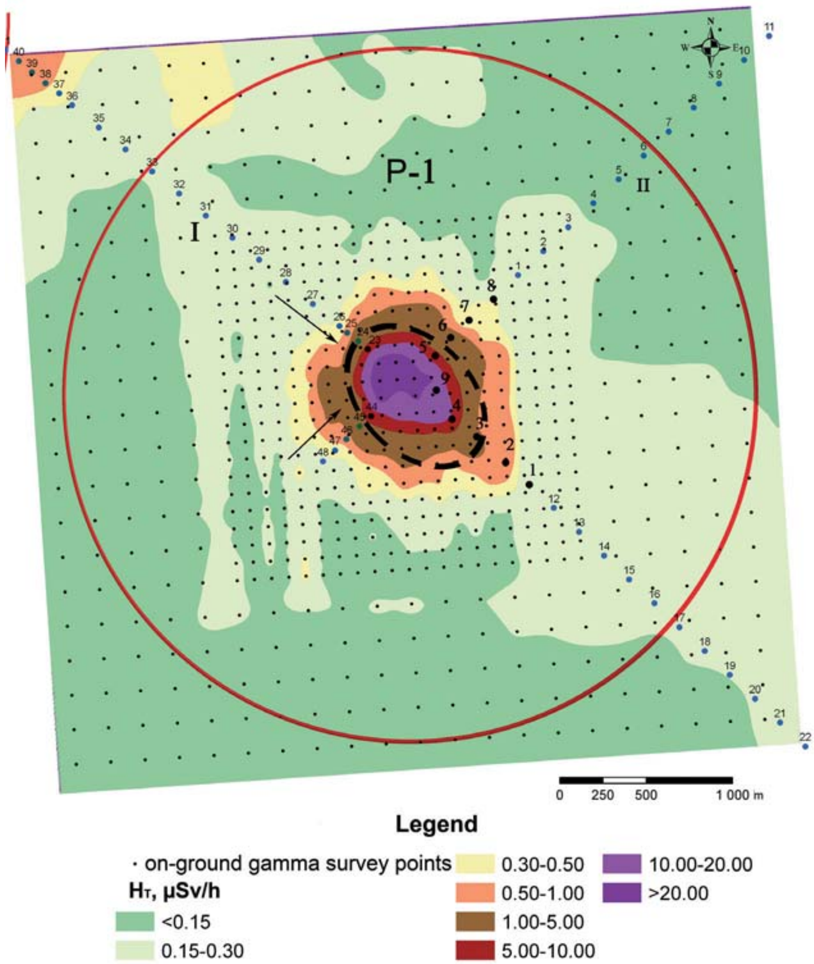


Figure 17. A map of EDR distribution on technical site P-1

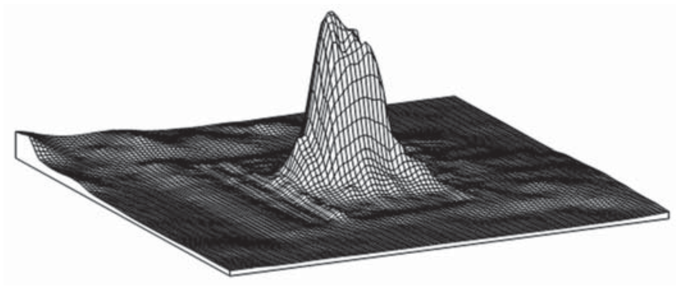
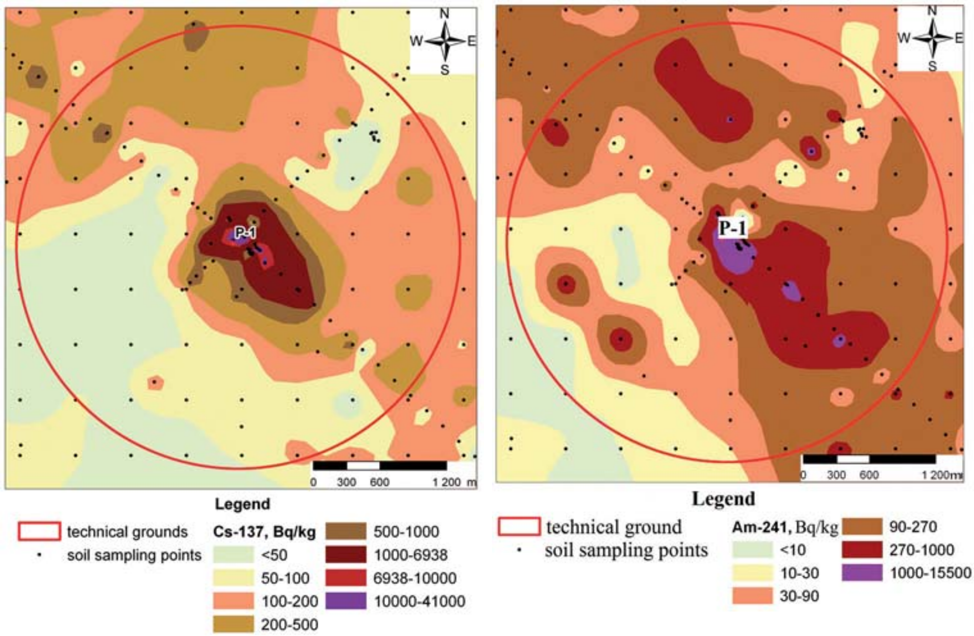


Figure 18. A three-dimensional map of EDR distribution over the technical site P-1



a) b)

Figure 19. Maps of ^{137}Cs and ^{241}Am distribution over the territory of the technical site P-1

To determine vertical distribution of artificial radionuclides and to estimate the volumes of radioactive wastes (RAW) two profiles for point and layerwise soil sampling were chosen (figure 17), points coordinates were identified and quantitative sample analysis was made. Then the distribution of concentrations of artificial radionuclides ^{241}Am, ^{137}Cs, ^{90}Sr and ^{152}Eu in the upper soil layer (0-5 cm) along profiles were plotted (figures 20-21). The directions of profiles on the map are shown by arrows. The character of contamination along profiles is not monotonous.

In profile I three contaminated zones were identified. The zone 0-2,000 m is likely to be formed by radioactive fallouts from tests on the other sites. The zone 2,000-3,000 m is characterized by low concentrations of artificial radionuclides comparable with the level of global fallouts. It can be explained either by no fallouts in the zone or by the above-mentioned reclamation, which is indirectly confirmed by the character of ^{241}Am distribution in profile II. It should be noted that the presence of ^{152}Eu in points of minimal concentration of fission products and ^{241}Am enables to suppose that reclamation was made before the thermonuclear test. Maximal concentration of artificial radionuclides was registered at a distance of 3,200-4,600 m and could be directly connected with the tests epicenter.

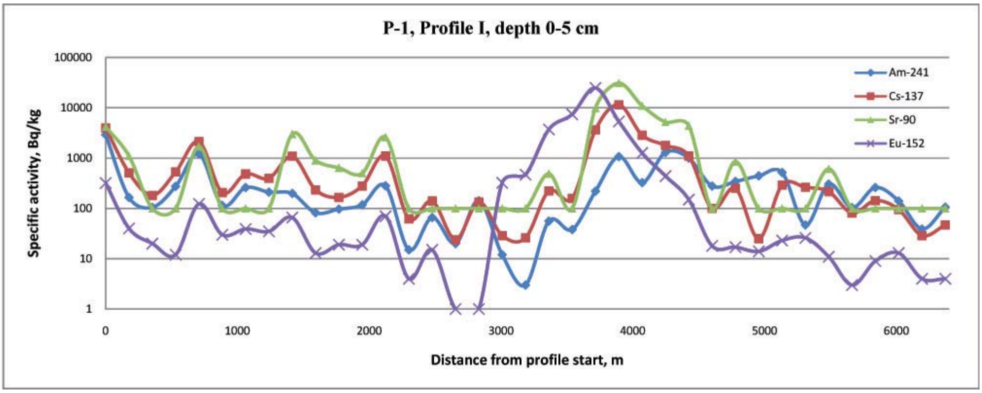


Figure 20. Distribution of specific activity of artificial radionuclides in profile I

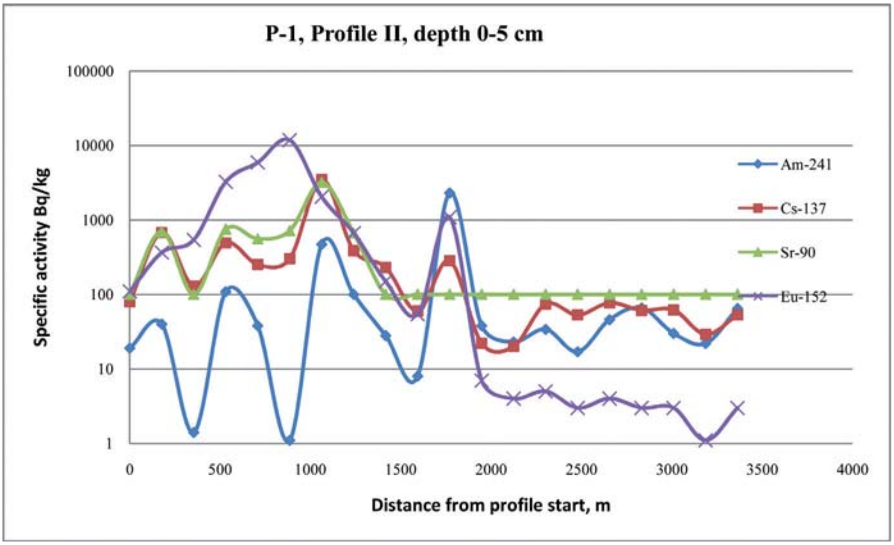


Figure 21. Distribution of specific activity of artificial radionuclides in profile II

Maximal concentration of the neutron activation product – ^{152}Eu is displaced relative to maximal concentrations of ^{90}Sr, ^{137}Cs and ^{241}Am. It is probably caused by radioactive fallouts displaced from the explosion epicenter. The direction of fallout was 130 degrees, which coincided with the wind direction during the 12.08.53 thermonuclear test of capacity 400kilotons in TNT equivalent.

An analysis of laboratory studies of surface soil layer on the technical site P-1 identified the following main contaminants – Cs^{137}, Sr^{90} and ^{152}Eu. The average coefficient of ^{152}Eu/^{60}Co ratio in the epicenter zone is 64, which decreases with the increase in the distance from the epicenter.

Table 7 presents the values of specific activity of artificial radionuclides in the epicenter zone of the technical site P-1.

Table 7.

Levels of specific activity of artificial radionuclides in the epicenter zone of the technical site P-1

Site	Values of specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	^{241}Am	^{152}Eu
P-1	from <1.3 to 11,510	from <100 to 31,000	from <1 to 1,300	from 150 to 24,850 in the surface layer and up to 9,500 at a depth of 20cm

It should be noted that high ^{152}Eu concentration (about 25000 Bq/kg) is the result of the thermonuclear explosion though 58 years, i.e. 4.5 half-life periods for the radionuclide, have passed since that time.

To describe the behavior of distributions of artificial radionuclides along the profile to a depth of 20cm we plotted a diagram of in-depth distribution of specific activity (for example, for ^{137}Cs) in the points of soil sampling in the epicenter zone (figure 22). The values of specific activity are normalized to the maximal value. As a rule, the highest concentration of artificial radionuclides is in the surface layer exponentially decreasing with depth.

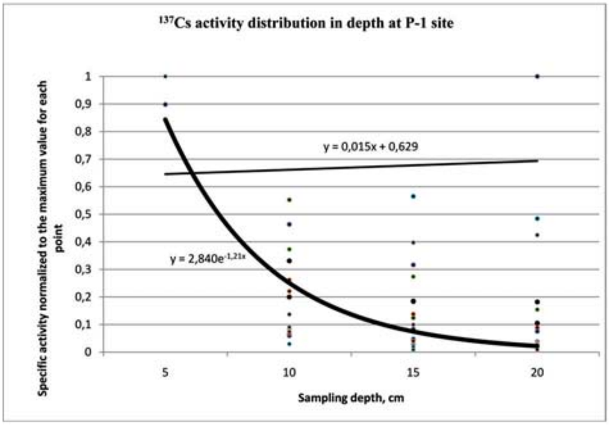


Figure 22. Distribution of Cs^{137} activity in the points of layered soil sampling to a depth of 0-20cm

The in-depth distribution of artificial radionuclides on the technical site P-1 mainly shows gradual activity decrease with depth and is well described by the exponential function $y=2.8e^{-1.2x}$ except points Nos. 23 and 24, where the above dependence is not observed, and to a certain depth the activity changes as a linear function $y = 0.016x + 0.63$. The values of concentrations in the points increased with depth. It is supposed that the points were in the zone of soil heap, which is not clearly revealed in this radiation-hazardous area as the explosion was made at a height of 30m. In figure 17 a dotted line shows an approximate boundary of the heap.

On the base of in-depth and areal distributions of artificial radionuclides the amount of radioactive wastes (RAW) on the technical site P-1 was estimated. The total RAW volume is about 70,000m^3. In calculations of RAW volume in $^{239+240}$Pu the average ratio $^{239+240}$Pu/^{241}Am was taken equal to 10.

On the technical site P-1 several spots with different structures of contamination were discovered. The main radiation-contaminated spot is an area of 1000m in diameter having a shape of a bulged-in crater without high rims, in the center of which ground waters outflow on the surface. The contamination was formed by three nuclear and one thermonuclear explosions. The latter explosion made the highest contribution to the radionuclide contamination of the epicenter zone. Based on the amount of accumulated activity of neutron activation products, one can state that the tested device had an extremely high capacity. However, taking into account different radiotoxicities of different artificial radionuclides, it is possible to conclude that the main contaminant of the technical site is ^{241}Am, and, hence, $^{239+240}$Pu. The presence of its high concentrations is probably caused by the first two tests on the technical site. The trace of radioactive fallouts spreads to a large distance in southwestern direction. In terms of external exposure (over 0.24 μSv/h) about 1.3 km^2 of the technical site are dangerous for people staying.

3.3. Investigations at the technical sites P-3 and P-5

3.3.1. Radiological situation on the territory of the technical sites P-3 and P-5

The test site P-3 was designated for atmospheric explosions of low and interim power, the site P-5 was made for high-yield atmospheric explosions. In addition to atmospheric tests, 7 ground nuclear tests were made at the sites – 4 tests at P-3 and 3 tests at P-5. Their characteristics are given in table 1.

Photographs of the epicenters of nuclear explosions on technical sites P-3 and P-5 are shown in figure 23.

Crater P-5 , spot No.1

Crater P-5 , spot No.1

Crater P -5 spot No.3

P-3, in the vicinity of the epicenter

Figure 23. Photographs of radiation-hazardous objects at technical sites P-5 and P-3

By the results of pedestrian gamma-survey the map of EDR distribution on sites P-5 and P-3 and in the areas adjacent to them was made (figure 24).

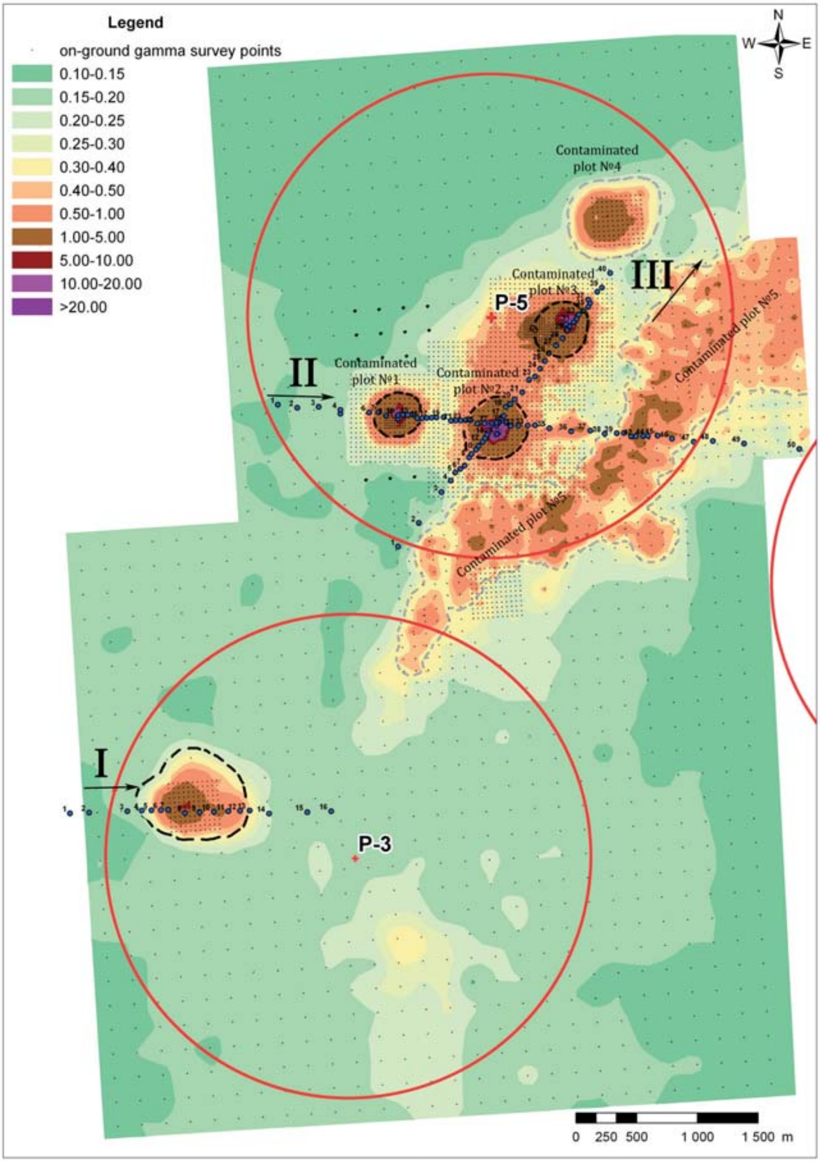


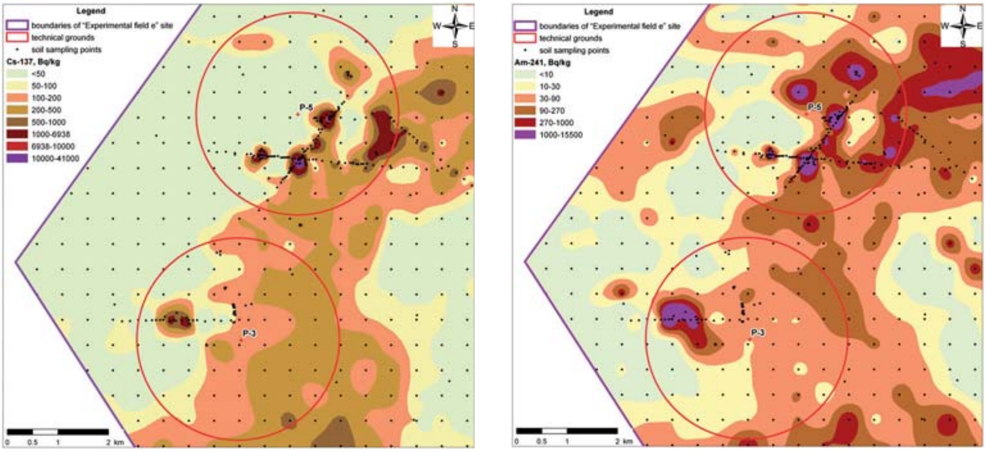
Figure 24. A map of EDR distribution on technical sites P-3 and P-5

Technical site P-5 has a high EDR level with values reaching 20µSv/h in all three zones. In three zones of object P-5 the area of contamination exceeding 0.24µSv/h is about 6 km^2. Taking into account that the area of object P-5 is 12.6 km^2, in terms of external exposure

47% of its territory refer to radiation-hazardous zones, and staying there must be limited. The epicenter zone of radiation-hazardous objects on site P-5 consists of three craters surrounded by radiation-hazardous area. The area of contaminated spot No.1 is about 0.7km^2, the area of spot No.2 – 1.4km^2 and spot No.3 is 1.6km^2. The other part of contamination is presented by the traces of radioactive fallouts of an area of about 2.3 km^2. Besides the above three craters on site P-, formed as a result of nuclear tests (24.08.56, 07.08.62, 25.09.62), 2 more spots of local radioactive contamination (figure 24) – spots No.4 and No.5 were detected. Spot No.4 is about 800m in diameter, by its shape and size it looks like another epicenter of nuclear test. To confirm or to reject this assumption it is necessary to carry out additional investigations. The area with EDR level ≥ 0.24μSv/h is equal to about 0.5km^2. Spot No. 5 is an elongated radiation-contaminated area. According to its location it can be a trace of radioactive fallouts from nuclear tests on site P-3. The area with EDR level ≥ 0.24μSv/h, where people staying must be limited, is equal to 1.8 km^2

Technical site P-3 has lower EDR level with values ranging from 0.10 to 10μSv/h. The epicenter zone of technical site P-3 is a radiation-contaminated area without any visible changes in the natural landscape. Maximum EDR values were registered at a distance of 150 meters to the west from the target white-clay cross. The contaminated area with EDR level over 0.24μSv/h, where people staying must be limited, is about 0.6 km^2, which makes about 4.8% of the total area of the technical site.

Figure 25 shows maps of areal distribution of artificial radionuclides ^{137}Cs and ^{241}Am on the territory of technical sites P-3 and P-5.



a) b)

Figure 25. Maps of ^{137}Cs and ^{241}Am distributions on the territory of technical sites P-3 and P-5

The next stage in inventory of radiation-hazardous objects located on technical sites P-3 and P-5 was to determine the volume of radioactive wastes concentrated on the sites. For this purpose three profiles for point and layered soil sampling (figure 24) were chosen, the coordinates of points were determined, and field works were carried out.

To study in detail changes of in-depth distributions of radionuclide concentrations with the distance from epicenters, we plotted distributions of activities of artificial radionuclides ^{241}Am, ^{137}Cs, ^{90}Sr and ^{152}Eu in the upper soil layer (0-5cm) along the profiles (figures 26-28).

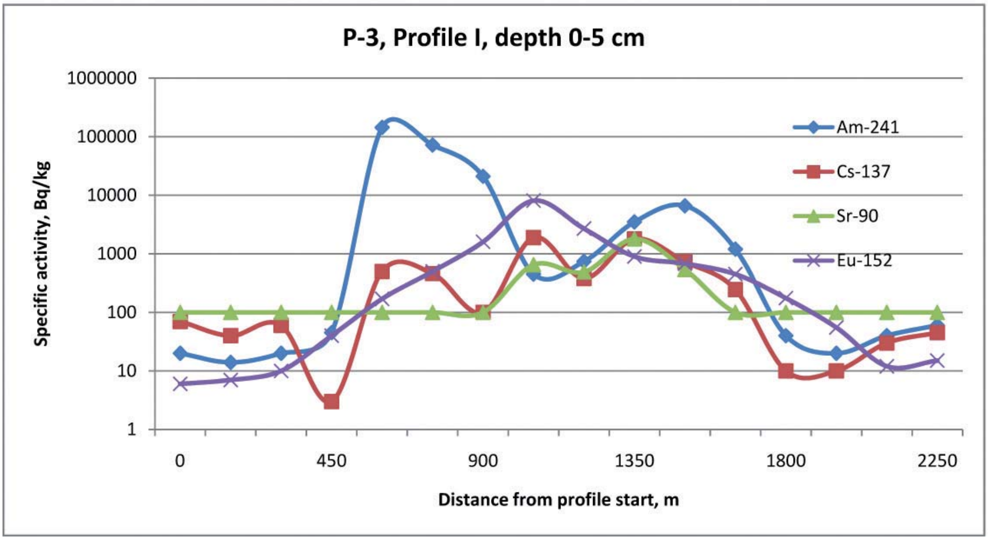


Figure 26. Distribution of specific activities of artificial radionuclides in profile I

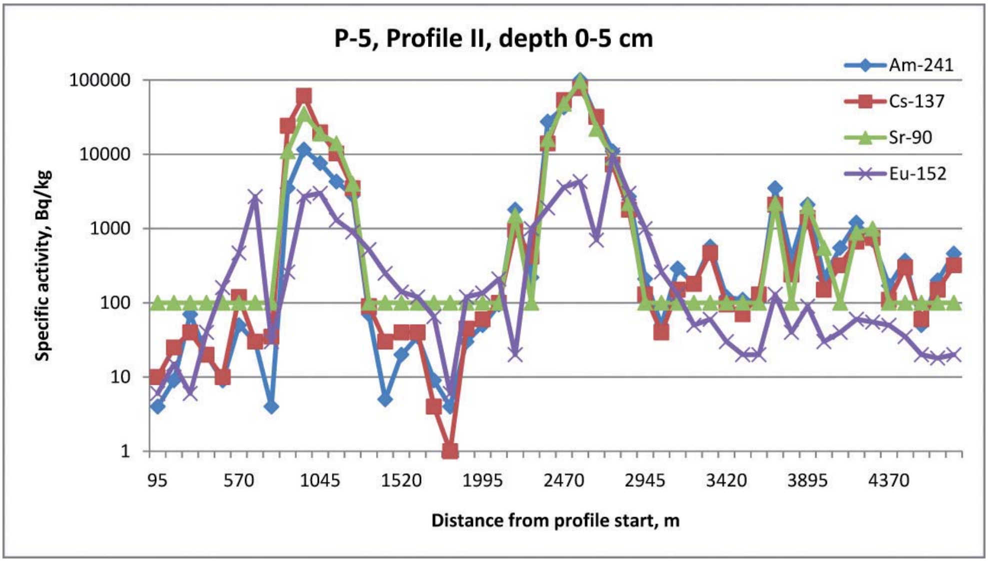


Figure 27. Distribution of specific activities of artificial radionuclides in profile II

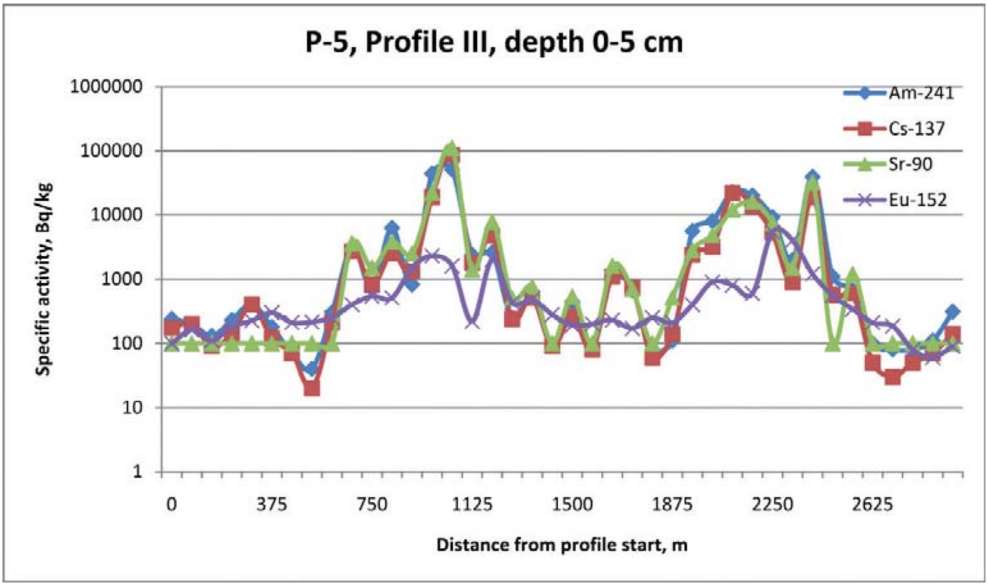


Figure 28. Distribution of specific activities of artificial radionuclides in profile III

As a result of laboratory analysis of the surface soil layer in profile I at the site P-3 the main contaminant – ^{241}Am was identified. It should be noted that maxima of ^{241}Am contamination are displaced to the left and to the right relative to the maximum of neutron activation products. The point of maximum ^{152}Eu concentration can be conventionally taken as the explosion epicenter. In the epicenter, the level of contamination with ^{241}Am and fission products decreases for orders of magnitude. ^{137}Cs distribution in the epicenter zone is more uniform and decreases to background values at a distance of 500 meters from the epicenter. High ^{152}Eu concentrations in the epicenter gradually decreasing to the profile ends indicate large spatial angle of incident fast neutrons (one of the explosions was made by bombing at a height of 50m). The average coefficient of ^{152}Eu/^{60}Co ratio is 70.

In profiles II and III on the site P-5, soil radioactive contamination is caused by the presence of ^{137}Cs, ^{241}Am and ^{90}Sr. The results of investigations of layered soil samples, giving the main characteristics to a depth of 20cm, were used to plot the graphs of in-depth distributions of specific activity (on the example of ^{137}Cs) in the sampling points No. 5, 6, 7, 13, 14 and 15 (P-5, spot No.1) and in points No. 26 and 27 (P-5, spot No.2). The dependence of specific activity on depth is shown in figure 29. To make the dependence more clearly seen the activity in diagrams is normalized to the maximal value of specific activity. The location of points on the object is shown in figure 24.

The diagram shows that in-depth distribution of radionuclide concentrations can be described by an exponential function $y=2e^{-0.80x}$. However, there are zones where the distribution of radionuclide concentrations does not follow the above dependence. The radionuclide concentration either increases till a certain depth (which can be described by a linear function $\gamma=\alpha\cdot x+b$) or does not change and then decreases by the exponential law (figure 29). As the sampling depth increases, the activity does not change noticeably, but in some points it increases which can be caused by heap, i.e. by the layer of different thickness with certain activity of radionuclides which was formed after nuclear tests. The laboratory data confirm the existence of such zones.

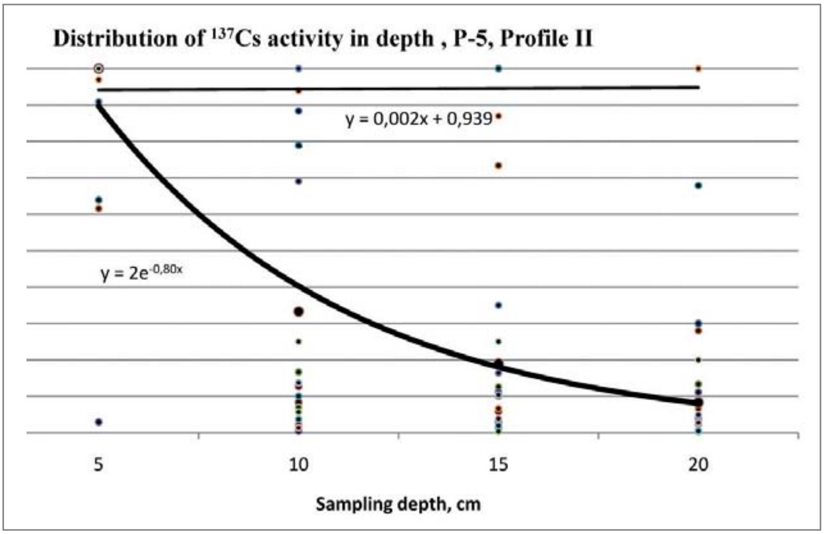


Figure 29. In-depth distribution of Cs-137 specific activity

The photograph (figure 30) shows a soil profile made very close to the epicenter of explosion (P-5, spot No. 2). In this area the 20cm heap is identified visually.

Figure 30. Soil heap

To characterize the places of soil heaps in the diagrams (figures 31-32) we showed in-depth distribution of ^{241}Am, ^{137}Cs, ^{90}Sr and ^{152}Eu concentrations in point No.10, spot 1, and point No.28, spot 2 (points of soil heap) to a depth of 1m. Point No.10 is on the rim of the crater, point No.28 is at a distance of 50m from the rim.

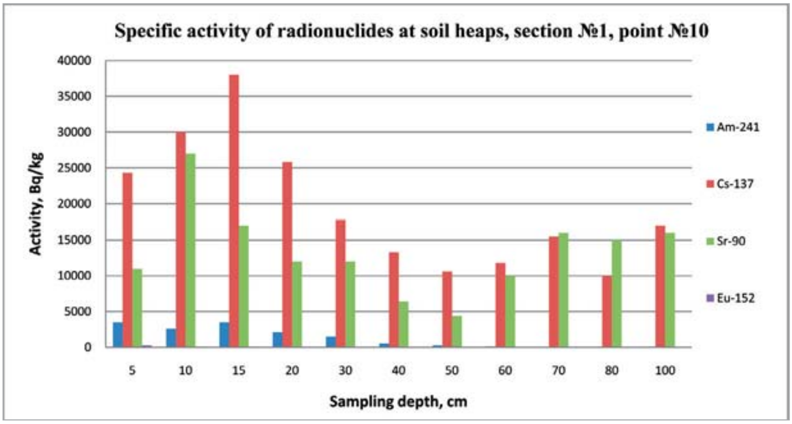


Figure 31. In-depth distribution of radionuclide specific activity in the point of soil heap

As it is seen from the diagram specific activity of ^{90}Sr and ^{137}Cs in the points of soil heap remains equal to 16,000 Bq/kg, with concentration of neutron activation products close to zero.

Careful studying of spot No.2, site P-5, point No.28 shows the other picture. The level of activation of the main artificial radionuclides decreases by the exponential law. The only exception is ^{152}Eu, whose specific activity increases to a depth of 20cm and then decreases but not exponentially (figure 32). The above results enable to suppose that the cross-section of neutron interactions with soil substance in the capture reaction (n, y) increases after passing some soil layers, i.e. when neutrons are slowed down.

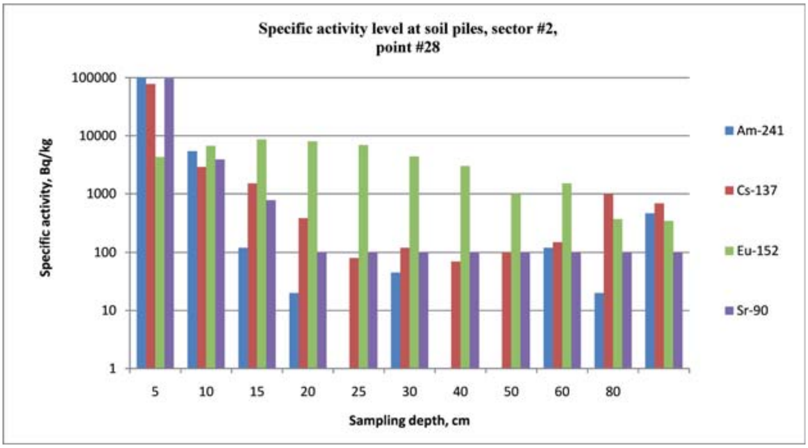


Figure 32. In-depth distribution of specific activity in the point of soil heap

The above data enable to make an assumption that in the zone of soil excavation (crater rim, point No.10) the concentration of neutron activation products is about zero. At a distance of tens of meters it reaches maximal values.

Thus, in most points the vertical radionuclide distribution shows gradual decrease with increase in the depth of soil layer. However, this tendency is not observed everywhere, which is confirmed by the data in points 10, 11, 28 and 29 (P-5, profile II, spots 1, 2). This fact must be taken into account is calculations of RAW volumes. Figure 24 shows approximate boundaries of heaps located on the studied profiles. The values of specific activity of artificial radionuclides in the studied areas are given in table 8.

Table 8.

Levels of specific activity of artificial radionuclides in the studied areas

Site	Specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	^{241}Am	^{152}Eu
P-3	from <0.2 to 1,900	from <100 to 2,000	from <4 to 144,000	from <1 to 9,800
P-5, spot No.1	from <1 to 61,600 in the surface layer and to 100,000 at a depth of 10 cm	from <100 to 35,000	from <4 to o 11,600	from <1 to 2,300
P-5, spot No.2	from <1 to 86,000	from <100 to 110,000	from <4 to 100,000	from <1 to 2,300 in the surface layer and to 5,400 at a depth of 20 cm
P-5, spot No.3	from <3 to 22,000	from <100 to 32,000	from <6 to 39,300	from <1 to 5,400 in the surface layer and to 9,500 at a depth of 20 cm

A survey of the territory of technical sites P-3 and P-5 determined 6 radiation-hazardous zones. Zones No.1, 2 and 3 are craters filled with ground waters and surrounded by a 100-300 m radiation-hazardous area. Zones No.2 and 3 are connected forming one elongated contaminated zone along 0.5 isoline with activity of 1 μSv/h. This zone was most probably formed by radioactive fallouts after the explosion made in zone No.3. The so called "heaping zones", where in-depth distribution of artificial radionuclide concentrations does not follow the exponential law and practically does not change with depth, where detected. Rough boundaries of the areas were determined. A considerable amount on slag up to 7 cm thick was detected on the crests of crater rims.

The origin of the zone No.4 causes interest as it could be formed as a result of a nuclear test, which is difficult to identify now. The contaminated area has a round shape with high EDR levels exceeding 5μSv/h in some points. By radionuclide composition the area has high concentrations of activation products, fission products and transuranium elements. The fragments of fused soil were found there.

A radiation-hazardous area of 1km in diameter was discovered on the territory of the technical site P-3, it does disturb the landscape and is considerably displaced from the center of the technical site to the north-west in the direction of the white-clay target cross. The activity in the center of the area EDR goes up to 10 μSv/h. The area has high concentration of ^{241}Am and ^{152}Eu. The contaminated area with EDR level over 0.24 μSv/h, where people staying must be limited, is about 0.6 km^2. No considerable relief changes caused by the explosion were discovered. In the place of explosion "slag fields" of about 100m in diameter were detected.

5 radiation-hazardous zones were revealed on the territory of the technical site P-5. Zones No. 1, 2, 3 are craters located at approximately equal distance, about 1,200m, from each other, surrounded by radiation-contaminated area with transverse dimensions varying from 700 to 1100 m with EDR levels over 20 µSv/h. Zone No. 4 is supposed to be the place of the fourth test on P-5, its diameter is about 800m, and EDR level equals to 5 µSv/h. Zone 5 is an elongated trace of radioactive fallouts with EDR reaching 10µSv/h. The total contaminated area summed up over all spots on P-5 is equal to 6 km^2.

Based on the distribution of artificial radionuclides in the upper soil layer, we estimated RAW volumes on the technical sites. The total RAW volume in radiation-hazardous zones of technical sites P-5 and P-3 is presented in table 9. In RAW calculations in $^{239+240}$Pu the average $^{239+240}$Pu/^{241}Am ratio was taken equal to 10.

Table 9.

RAW volumes on technical sites P-5 and P-3

Object	RAW volume, m^3
P-5, Spot No.1	15,000
P-5, Spot No.2	60,000
P-5, Spot No.3	40,000
P-3	57,000

3.4. Investigations at the technical sites P-2, P2-G and P-7

3.4.2. Radiological situation at the territory of technical sites P-2, P2-G and P-7

P-2 site was designated for nuclear explosions of capacity of 1.3-14 kilotons. 6 nuclear tests including 1 test without nuclear explosion regime (the device did not explode) were made there. The characteristics of tests are given in table 1. The first unexploded charge made a considerable contribution to the contamination of the technical site – 215Ci of plutonium were released in the test [7].

P-7 site was designated for nuclear explosions of low capacity (from 0.007 to 0.4 kilotons) at a height of 0 meters. 12 nuclear explosions were made there in the period from 09.09.1961 to 24.12.1962, in 4 cases the nuclear devices did not explode [7].

On the territory of site P2-G, located on the territory of sites P-2 and P-7, hydronuclear explosions – explosions with nuclear charges, where the amount of released nuclear energy is comparable with the energy of chemical explosives, were made. In the 1958-1963 period, 40 model experiments were made, the difference in alpha-activity release in the experiments was as high as 400 [1]. The total amount of plutonium alpha-activity dispersed in hydronuclear experiments was 800-900Ci. The main characteristics of hydronuclear experiments are presented in table 2.

P-2 and P-7 sites were also areas of hydrodynamic tests – explosion experiments with nuclear charges in which nuclear energy was not released (table 7). They do not refer to nuclear tests but they considerably contributed to the contamination of the studied area. In the period from 1954 to 1962, 5 such tests were made, as a result about 1,000Ci of plutonium

P-2, spot No.10. A crater, 25m in diameter, filled with water

P-2, spot No. 11. A crater, 25m in diameter, over 10m deep, filled with water

A round-shape crater of 30m in diameter, 12m deep, bottom is rushy with water

A round-shape crater of 30m in diameter, 10-12m deep, bottom is rushy with water

A round-shape crater of 20m in diameter, 5-7m deep, bottom is overgrown with grass

A crater of 20m in diameter, 6m in depth

Figure 33. Photographs of some epicenters in the radiation-hazardous zones at technical sites P-2, P2-G and P-7

[1] were released to the atmosphere. The main characteristics of hydrodynamic experiments are presented in table 3.

Photographs of the epicenters of some areas are shown in figure 33. It is seen that the epicenters of high-capacity explosions are craters with either outcomes of ground waters or signs of their close location. It is rather difficult to discover epicenter zones of low-capacity explosions.

Based on the integral radiation parameters there are 11 radiation-contaminated zones with high EDR level on technical sites P-2, P2-G and P-7. The total contaminated area with EDR exceeding 0.24 μSv/h, where people staying must be limited, is about 4.3 km^2, which makes about 20% of the total area of the technical sites equal to 21km^2. The map of EDR distribution on the territory of sites P-2, P2-G and P-7 is shown in figure 34. The main characteristics of contaminated areas are presented in Table 10.

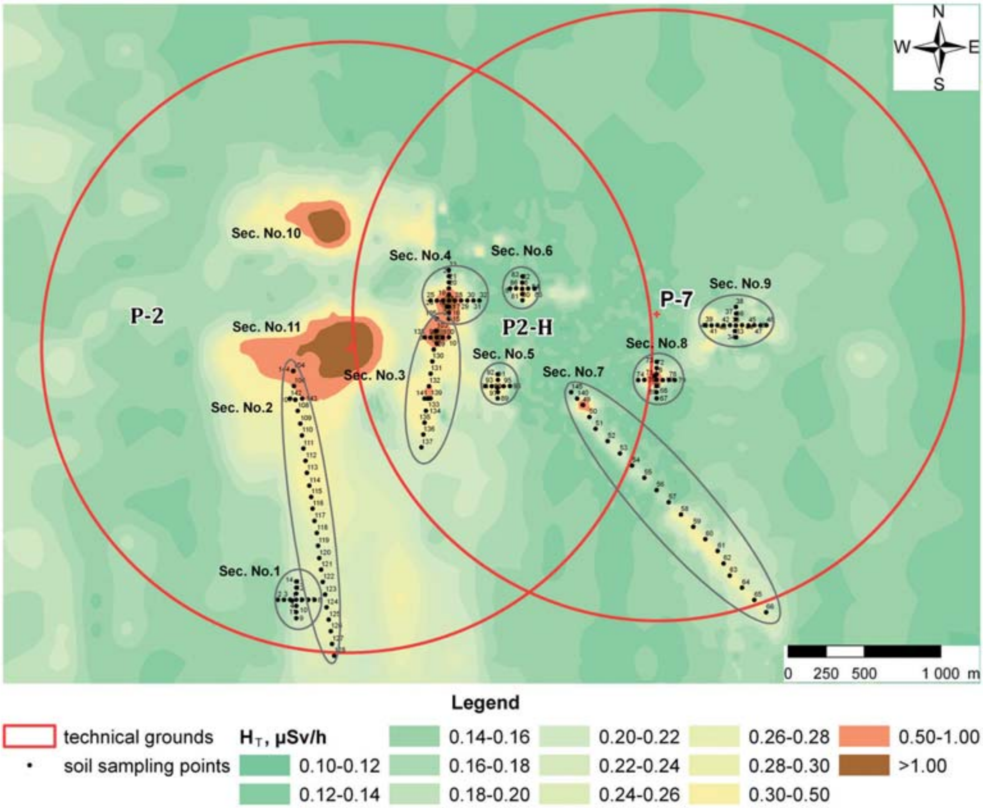


Figure 34. A map of EDR distribution on the territory of sites P-2, P2-G and P-7

Table 10.

Characteristics of contaminated areas

Zone number	Maximal EDR level, µSv/h	Area of the territory with EDR exceeding 0.24 µSv/h	Remarks
Zone No.1	0.28	0.01	
Zone No.2	0.5	about 1km^2	The zone is a superposition of several traces of radioactive fallouts
Zone No.3	4.0	about 0.12 km^2	
Zone No.4	2.7	about 0.12 km^2	The zone is supposed to be the place where several hydronuclear explosions were made
Zone No.5	1.0	about 0.04 km^2	
Zone No.6	1.0	about 0.03 km^2	
Zone No.7	2.5	about 0.7 km^2	A narrow (70-80m) trace of radioactive fallouts with EDR values up to 5 µSv/h stretching to the southeast to a distance of 1.5 km
Zone No.8	1.6	about 0.05 km^2	
Zone No.9	0.5	about 0.09 km^2	
Zone No.10	23.4	about 0.7 km^2	The zone is a 10m-deep crater of 40 m in diameter with outcome of ground waters. The crater is surrounded by a radiation-contaminated area.
Zone No.11	5.83	about 0.7 km^2	The zone has two craters of 25 m in diameter located at a distance of 150 m from each other with outcome of ground waters. The craters are surrounded by a radiation-contaminated area displaced relative to the epicenters to the southwest.

Taking into account specific character of the tests the EDR map in this case does not enable to estimate real scales of contamination. Figures 35-36 shows maps of ^{137}Cs and ^{241}Am distributions on the territory of sites P-2, P2-G and P-7. To get a more precise picture of the areal distribution of ^{241}Am и ^{137}Cs on the territory of the sites all available data including the data obtained in the framework of ISTC project K-337 were plotted in the figure.

To get more detailed information about the scales of contamination the soil samples were taken along profiles (figure 34) passing through epicenter zones along the traces of radioactive fallouts almost in all detected areas. To study distributions of radionuclide concentrations in more details the diagrams of distributions of artificial radionuclides ^{241}Am, ^{137}Cs, ^{90}Sr and ^{152}Eu activities in the upper soil layer (0-5cm) along profiles were made. The profiles characterize the main contaminated zones. The diagrams of distributions of artificial radionuclides concentrations in profiles points were plotted from down to up and from left to right.

To estimate vertical migration of artificial radionuclides in the studied area, in the central points of intersecting profiles trenches were dug and layerwise samples were taken. The results are presented as diagrams.

Zone No.1 characterizes western part of radioactive fallouts of southern direction spreading from the center of technical site P-2 (figure 37). The in-depth distribution of radionuclides concentration follows an exponential dependence (figure 38).

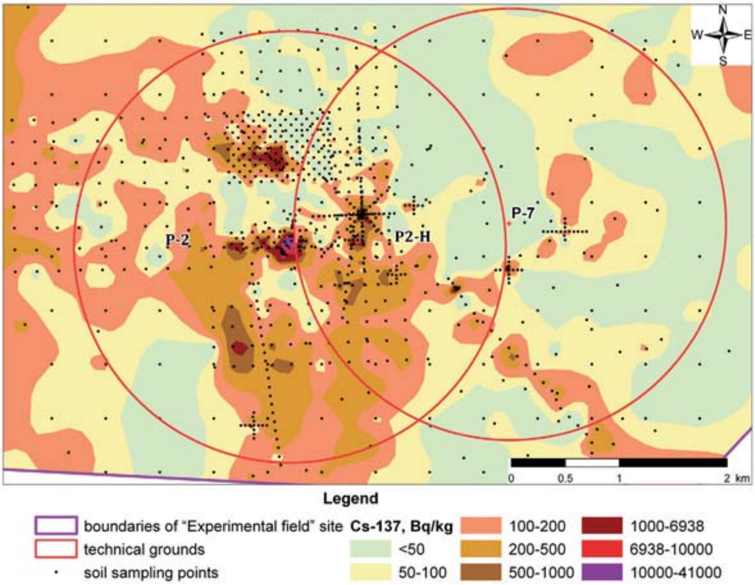


Figure 35. A map of ^{137}Cs distribution over the territory of technical sites P-2, P2-G and P-7

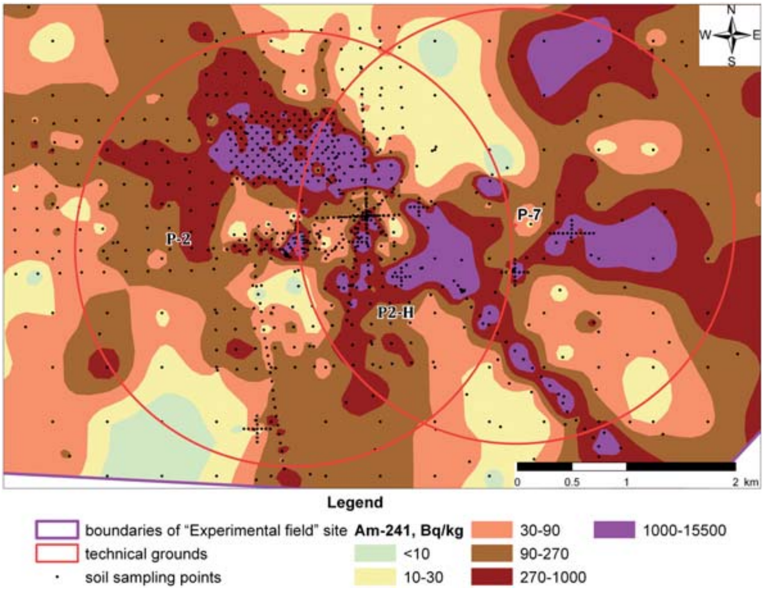


Figure 36. A map of ^{241}Am distribution over the territory of technical sites P-2, P2-G and P-7

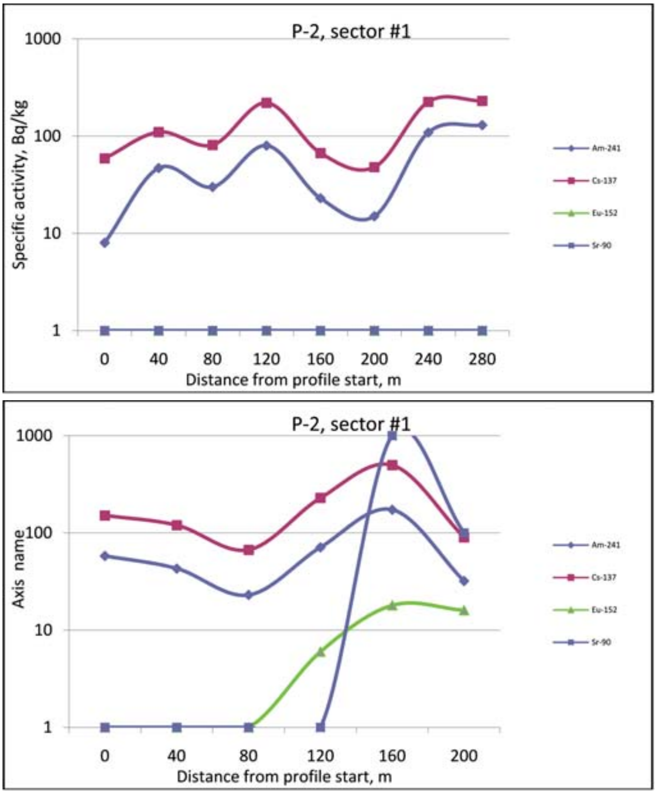


Figure 37. Distribution of specific activity of artificial radionuclides in zone No.1

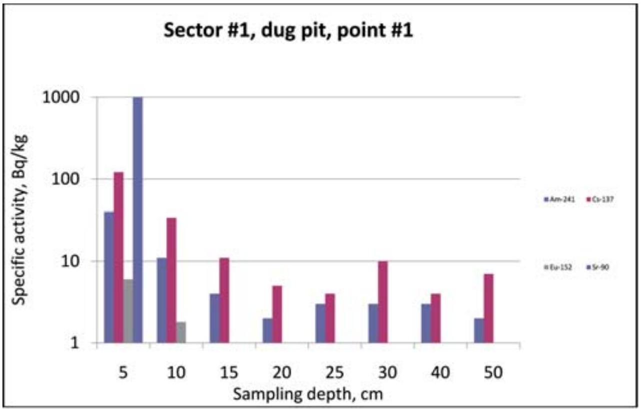


Figure 38. In-depth distribution of specific activity of artificial radionuclides

Zone No.2 is an elongated trace of radioactive fallouts stretching to the south on technical site No.2. Radionuclide concentrations do not exceed MSSA. As one moves closer to zone No.11, where the nuclear test was made, a sharp increase in ^{152}Eu concentration is registered (figure 39).

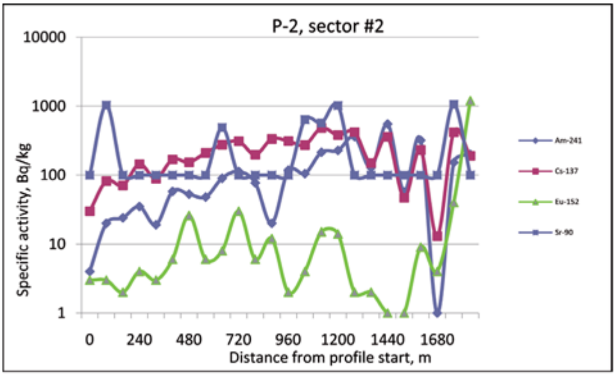


Figure 39. Distribution of specific activity of artificial radionuclides in zone No.2

Zone No.3 is a trace of radioactive fallouts presumably passing through two epicenters. The amount of accumulate activity of artificial radionuclides is rather small (figure 40). The in-depth distribution of radionuclides concentration follows an exponential dependence (figure 41).

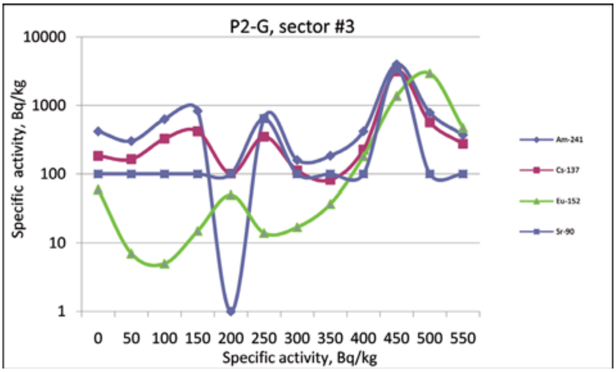


Figure 40. Distribution of specific activity of artificial radionuclides in zone No.3

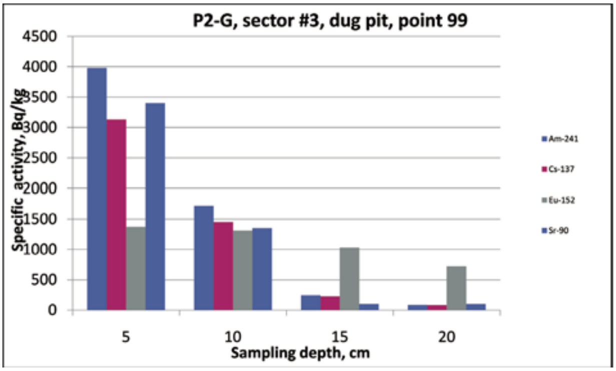


Figure 41. In-depth distribution of specific activity of artificial radionuclides

Zone No.4 is located very close to zone No.3, the contaminated area occupies larger territory – about 0.1km^2 is contaminated with ^{152}Eu. The area of 200m in radius located around the epicenter – the point of maximal concentration is contaminated with ^{152}Eu (figure 42). Based on the character of ^{152}Eu distribution one may suppose that the test was made at some height. The in-depth distribution of radionuclides concentration follows an exponential dependence (figure 43).

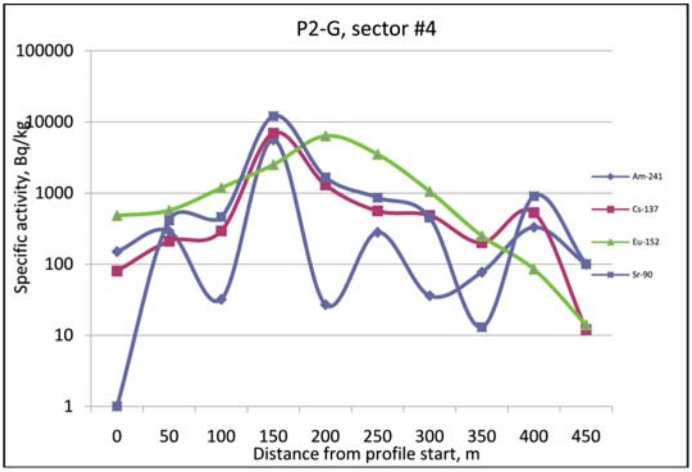


Figure 42. Distribution of specific activity of artificial radionuclides in zone No.4

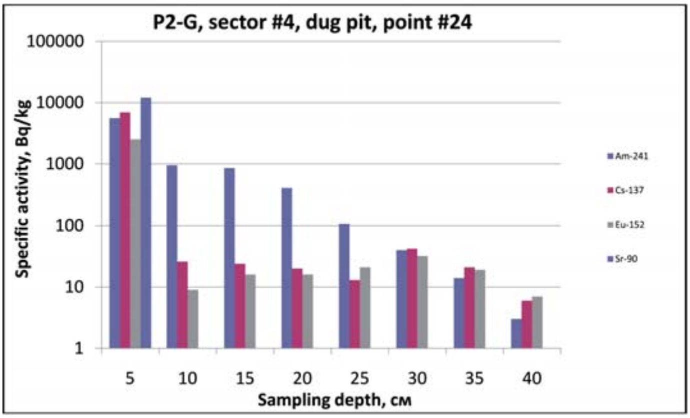


Figure 43. In-depth distribution of specific activity of artificial radionuclides

Zone No.5 is the epicenter of a test. The amount of accumulated ^{152}Eu activity is rather high, its concentration reaches 8,000 Bq/kg (figure 44). The levels of concentrations of fission products and the character of their distribution enable to suppose that they were formed as a result of the other test whose epicenter was in zone No.6. Maximal concentration of activation products corresponds to minimal concentration of fission products and ^{241}Am. The in-depth distribution of radionuclides concentration follows an exponential dependence (figure 45).

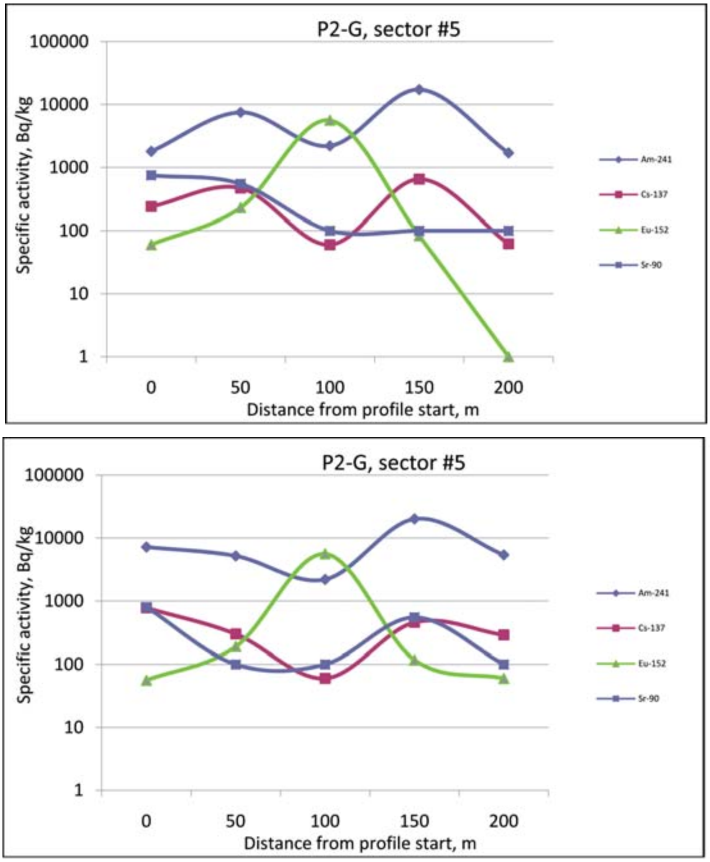


Figure 44. Distribution of specific activity of artificial radionuclides in zone No.5

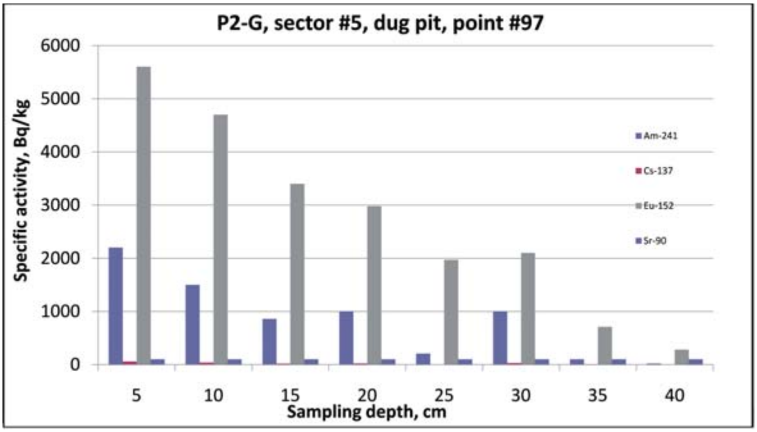
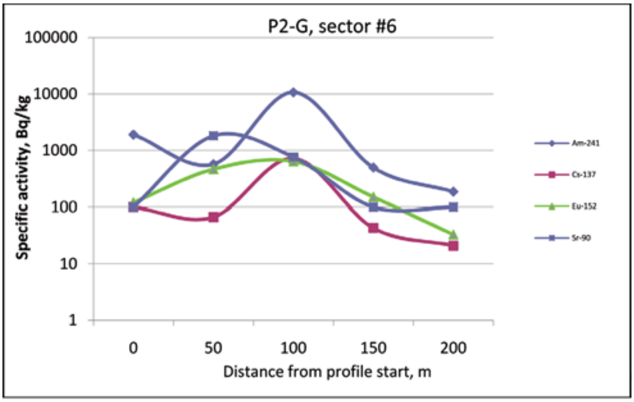


Figure 45. In-depth distribution of specific activity of artificial radionuclides

In zone No.6 the presence of activation products is less pronounced, but ^{241}Am concentration is at a high level (figure 46). The in-depth distribution of radionuclides concentration follows an exponential dependence (figure 47).



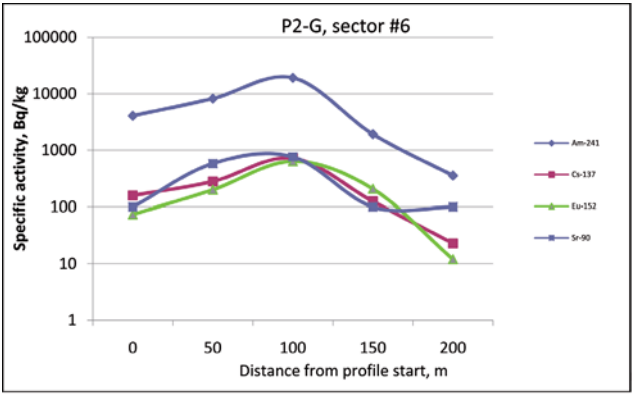


Figure 46. Distribution of specific activity of artificial radionuclides in zone No.6

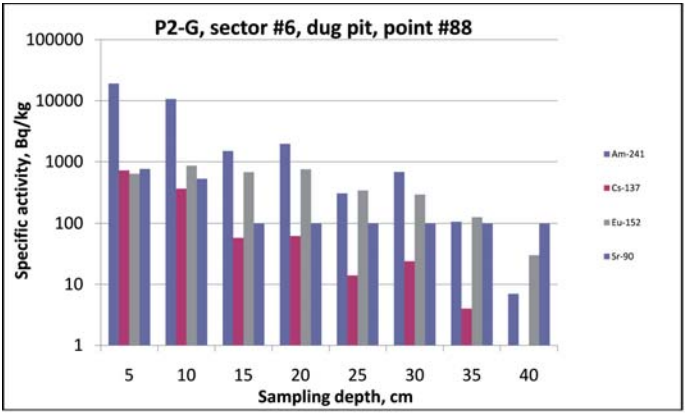


Figure 47. In-depth distribution of specific activity of artificial radionuclides

Zone No.7 is an epicenter presumably produced by a nuclear test that formed a 100m wide trace of radioactive fallouts stretching for 2km in southeastern direction. The amount of accumulated activity of ^{152}Eu in the epicenter is rather high and reaches 7,000 Bq/kg. Maximal concentration of activation products in the epicenter corresponds to maximal concentration of fission products and ^{241}Am (figure 48). The in-depth distribution of radionuclides does not follow an exponential dependence. At a depth of 40m high concentration of ^{152}Eu and ^{241}Am with values of 900 Bq/kg and 1,200 Bq/kg, respectively, were registered, which probably corresponds to the heaping zone (figure 49).

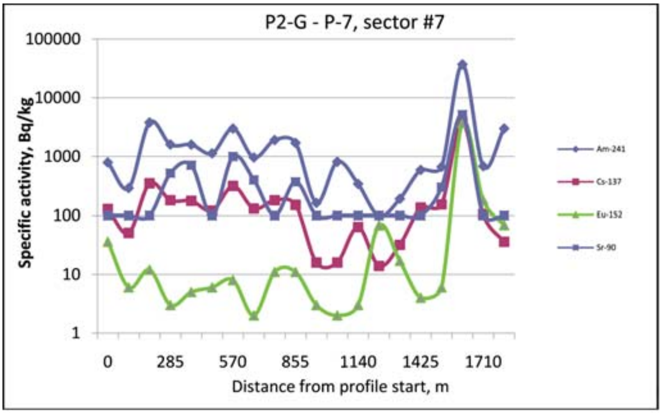


Figure 48. Distribution of specific activity of artificial radionuclides in zone No.7

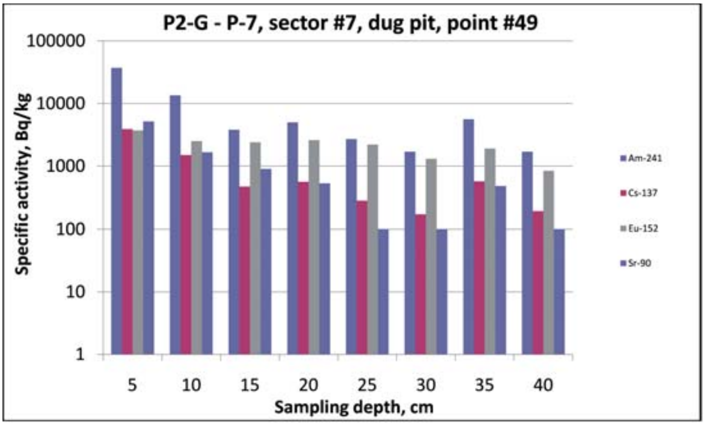


Figure 49. In-depth distribution of specific activity of artificial radionuclides

Zone No.8 is an epicenter probably formed by a high-capacity explosion. The amount of accumulated activity of ^{152}Eu in the epicenter is rather low and does not exceed 900 Bq//kg (figure 50). The in-depth distribution of radionuclides does not follow an exponential dependence, which may be an indication of the heaping zone. At a depth of 40m high concentration of all radionuclides was registered, but ^{241}Am specific activity did not exceed MSSA (figure 51).

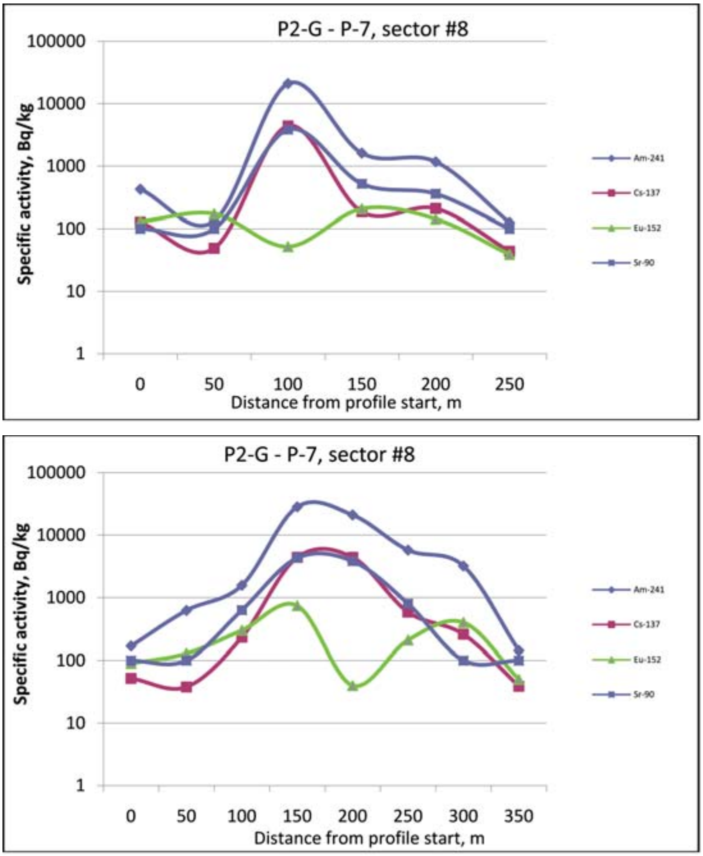


Figure 50. Distribution of specific activity of artificial radionuclides in zone No.8

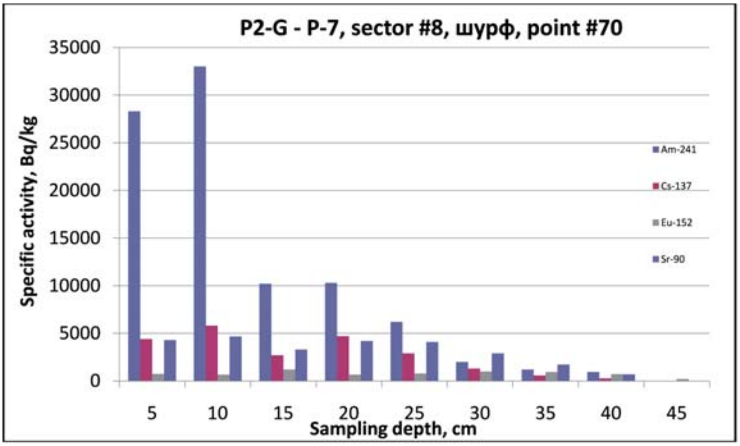


Figure 51. In-depth distribution of specific activity of artificial radionuclides

Zone No.9 has an elongated shape, the character of contamination along the profile and the ratios of ^{241}Am, ^{137}Cs and ^{152}Eu concentrations enable to suppose that the zone was formed by fallouts from several tests, and in some tests fission products were not formed. The zone has high contamination in ^{241}Am, and, hence, in $^{239+240}Pu$ (figure 52) to a depth of 30cm. The in-depth distribution of radionuclides does not follow an exponential dependence, which indicates presence of the heaping zone (figure53).

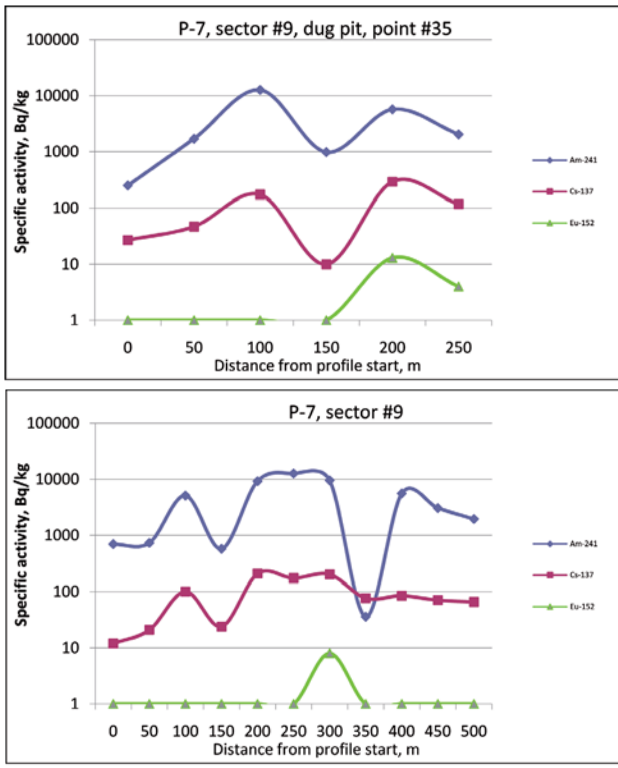


Figure 52. Distribution of specific activity of artificial radionuclides in zone No.9

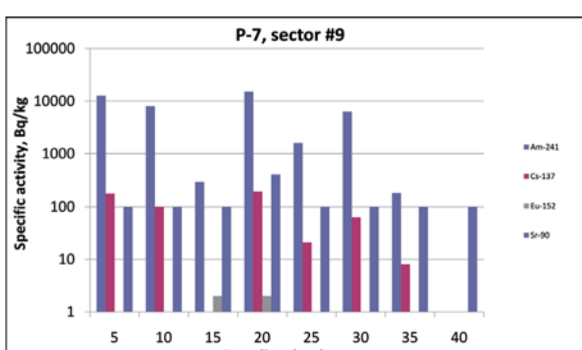


Figure 53. In-depth distribution of specific activity of artificial radionuclides

No detailed investigations for zones No.10 and 11 have been done yet.

Table 11 presents values of specific activity of artificial radionuclides in the studied areas.

Table 11.

Values of specific activity of artificial radionuclides

Site	Specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	^{241}Am	^{152}Eu
P-2, zone No.1	from <1 to o 497	from <100 to 1,000	from <1 to 170	from <1 to 18
P-2, zone No.2	from <1 to 480	from <100 to 3,400	from <1 to 550	from <1 to 3
P2-G, zone No.3	from <1 to 3,100	from <100 to 1,000	from 5 to 4,000	from <1 to 3,000
P2-G, zone No.4	from <1 to 6,900	from <100 to 12,000	from <1 to 5,600	from <1 to 6,300
P2-G, zone No.5	from <1 to 780	from <100 to 800	from 20 to 20,000	from <1 to 5,600
P2-G, zone No.6	from <1 to 720	from <100 to 1,800	from 7 to 20,000	from 12 to 860
P2-G – P-7, zone t No.7	from 14 to 3,900	from <100 to 800	from 98 to 37,000	from <1 to 3,600
P2-G – P-7, zone t No.8	from 38 to 5,800	from <100 to 4,700	from 125 to 33,000	from <1 to 1,200
P-7, zone No.9	from <1 to 290	from <100 to 500	from <1 to 15,000	from <1 to 13

Based on the array of information obtained in investigations of the radiological situation on the territory of technical sites P-2, P2-G and P-7, one can state that the main source of radionuclide contamination of the territory is ^{241}Am and, hence, $^{239+240}$Pu. Taking into account that the average ratio $^{239+240}$Pu/^{241}Am is 10, it was estimated that total RAW reserves on the technical sites are not less than 500,000 m^3, and the RAW area occupies about 50% of the total area of technical sites P-2, P2-G and P-7, i.e. 10.5km^2. A rather labor-intensive task was identification of all epicenters of former tests on the technical sites. Some of them could be identified by a high concentration of ^{152}Eu, or in some cases, by a high concentration of ^{241}Am.

4. DISCUSSION OF RESULTS AND CONCLUSIONS

All complex of obtained results enable to give general characteristics of the character and mechanisms of "Experimental field" contamination. By integral radiation parameters only a small part of the "Experimental field" can be classified as a radiation-contaminated area. The area with EDR exceeding 0.24μSv/h is about 11 km^2, i.e. 3% of the total area of the "Experimental field".

Several zones that can be identified as "epicenters" of nuclear explosions were detected. As a rule, the soil in the epicenters and adjacent areas has high concentrations of artificial radionuclides. Concentration of artificial radionuclides in radial direction changes exponentially and at distance of 300-500 meters practically decreases to background levels. At the same time, it should be noted that though all epicenters have common characteristics, each epicenter has its own "radionuclide portrait", different from the others, mainly by the ratios of concentrations of different radionuclides and their isotopes. Areas with the other type of contamination that can be called "areal" contamination were detected. The most probable mechanism responsible for formation of such areas is superposition of fallouts from several nuclear tests. The zones are characterized by conventionally uniform distribution of concentrations of artificial radionuclides on large territories sometimes as large as tens of square kilometers.

The products of ^{137}Cs and ^{90}Sr fission spread in three main directions: northeastern, southeastern and southwestern. The highest concentration of the above radionuclides is registered directly in the spots corresponding to former epicenters of nuclear explosions, which occupy relatively small areas not exceeding 1-2 square kilometers. On the other part of the "Experimental field" their concentrations are rather low, below n×10^3 Bq/kg.

A large amount of isotopes – fragments of fissile materials ^{241}Am и $^{239+240}$Pu is registered in epicenter zones of technical sites and in elongated traces of radioactive fallouts. As a rule, in the epicenter zone spots with high ^{241}Am concentration occupy small areas. In the spots of areal contamination, probably formed as a result of superposition of radioactive fallouts, ^{241}Am concentrations may be as high as n×10^4 Bq/kg like in the epicenter zones.

Besides fissile materials and fission products, the epicenters are the places of concentration of neutron activation products: Co^{60}, Eu$^{152, 154, 155}$, which, mainly, do not leave the boundaries of technical sites and can be used as indicators of nuclear tests.

These investigations enable to obtain general estimations of radioactive wastes amounts on the "Experimental field" site. The generalized results are given in table 12.

Table 12.

Generalized results on the extent, character of contamination and RAW amounts at the territory of the "Experimental field"

Object	Spot number	EDR$_{max}$, µSv/h	Specific activity $_{max}$, Bq/kg				Area with EDR≥ 0.24 µSv/h, km^2	Total RAW volume on the spot, m^3	Total RAW volume on the site, m^3
			^{137}Cs	^{90}Sr	^{152}Eu	^{241}Am			
Experimental field	-	15.4	41,000	140,000	18,000	16,000	11	-	2,000,000
P-1	1	>20	12,000	31,000	25,000	1,300	6	70,000	250,000
P-3	1	10.0	1,900	2,000	9,800	140,000	0.6	57,000	100,000
P-5	1	20.0	100,000	35,000	2300	12,000	0.7	15,000	150,000
	2	20.0	86,000	110,000	5400	100,000	1.4	60,000	
	3	20.0	22,000	32,000	9500	39,000	1.6	40,000	
	4	5.0	-	-	-	-	0.5	-	
	5	10.0	-	-	-	-	1.8	-	
P-2, P2-G, P-7	1	0.3	500	1,000	18	170	0,01	-	500,000
	2	0.5	480	3,400	3	550	1	-	
	3	4.0	3100	1,000	2,900	4,000	0.12	-	
	4	2.7	6,900	12,000	6,300	5,600	0.12	-	
	5	1.0	780	800	5,600	20,000	0.04	-	
	6	1.0	720	1,800	860	19,000	0.03	-	
	7	2.5	3,900	800	3,600	37,000	0.7	-	
	8	1.6	5,800	4,700	1,200	33,000	0.05	-	
	9	0.5	290	520	13	15,000	0.09	-	
	10	23	-	-	-	-	0.7	-	
	11	5.8	-	-	-	-	0.7	-	

Therefore, the total amount of RAW at all technical sites approaches to 1,000,000 m^3 with about half of the above volumes located beyond the territories of technical sites. Taking into account RAW volumes and the level of radiation hazard in terms of external irradiation, one can make a concussion that it is unreasonable to carry out restoration works except for the areas of point contamination located in the northern part of the "Experimental field". It should be taken into account that the contaminated spots stretch beyond the existing boundaries of the "Experimental field", therefore, more precise identification of the boundaries of such spots must become a priority direction in the works on the STS. Taking into account high radiotoxicity of transuranium elements, their high concentrations and large areas of contaminated territories, it is necessary to take measures preventing public access to the contaminated territories. The current boundaries of the "Experimental field" must be reconsidered, so that its new boundaries correspond to its current radioecological status.

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REFERENCES

1. Topical Issues in Radioecology of Kazakhstan [Radioecological State of "Northern" Part of the Semipalatinsk Test Site]/ edited by Lukashenko S.N. – iss. 1. – Pavlodar, Publishing house, 2010. – 36-45: ill. - Bibliography: p.224-231. - ISBN 978-601-7112-28-8.
   Актуальные вопросы радиоэкологии Казахстана [Радиоэкологическое состояние «Северной» части территории Семипалатинского испытательного полигона]/ под рук. Лукашенко С.Н. – Вып. 1. – Павлодар: Дом печати, 2010. – 36-45.: ил. - Библиогр.: С.224-231. - ISBN 978-601-7112-28-8.
2. Dubassov Yu.V. Model Assessment of Radiation Situation on the Altay Krai Territory. / Dubasov Yu.V. // Bulletin of the Center of Public Information on Atomic Energy: Special Publ. – Moscow: TsNIIAtominform, 1993. – No. 9. – p. 56.
   Дубасов Ю.В. Модельные оценки радиационной обстановки на территории Алтайского края. / Ю.В. Дубасов // Бюллетень центра общественной информации по атомной энергии: Спецвыпуск. – Москва: ЦНИИатоминформ, 1993. - № 9. – С. 56.
3. Andryushin I.A. Nuclear Tests in the USSR. Hydronuclear Experiments. Inventory of Plutonium Usage. / Andryushin I.A., Voloshin N.P., Il'kayev R.I. [et al.] // Bulletin of the Center of Public Information on Atomic Energy: Special Publ. – Moscow: TsNIIAtominform, 1998. – No. 12. – pp. 60-63.
   Андрюшин И.А. Ядерные испытания СССР. Гидроядерные эксперименты. Инвентаризация затрат плутония / И.А. Андрюшин, Н.П. Волошин, Р.И.

Илькаев [и др.]. // Бюллетень центра общественной информации по атомной энергии: Спецвыпуск. – Москва: ЦНИИатоминформ, 1998. - № 12. – С. 60-63.

4. Methods of Measurement of Gamma-Background of Territories and Premises: app. by RK Sanitary Epidemiological Service, 1997- 25-08. – p.4.
   Методика измерения гамма - фона территорий и помещений: утв. Санэпидстанцией РК 1997- 25-08. – 4 с.
5. GOST 17.4.3.01-83. Nature Protection. Soils. General Requirements to Soil Sampling. – Intrd. 1984-01-07. //Compilation. Nature Protection. Soils. – M.: Standards Publ. House, 1998. – pp. 29-31.
   ГОСТ 17.4.3.01-83. Охрана природы. Почвы. Общие требования к отбору проб. - Введ. 1984-01-07. // Сборник. Охрана природы. Почвы. – М.: Изд-во стандартов, 1998. – С. 29-31.
6. GPS receiver Garmin rino520. Service manual.
7. Development of basic principles and choice of technology for liquidation of surface contamination and methods of limitation of secondary contamination of the Semipalatinsk Test Site territory: final technical report on ISTC project K-337 / manager Sirajet Hajectber. – Almaty: INP NNC RK, 2003. – p. 164.
   Разработка основ и выбор технологий ликвидации поверхностного загрязнения и способов ограничения вторичного загрязнения территории Семипалатинского Испытательного Полигона: заключительный технический отчет по проекту МНТЦ К-337 / менеджер Сиражет Хажекбер. – Алматы: ИЯФ НЯЦ РК, 2003. -164с.
8. Reference Book on Nuclear Technologies: [trans. from English] / F. Ran, A. Adamantiades, J. Kenton, Ch. Brown edited by V.A. Legasov. – M.: Energoatomizdat, 1989.
9. Dosimeters-radiometers MKS-AT6130, MKS-AT6130A, MKS-AT6130B, service manual.- Atomtekh: Scientific-Production Unitary Enterprise. – p.84.
   Дозиметры-радиометры МКС-АТ6130, МКС-АТ6130А, МКС-АТ6130В, руководство по эксплуатации.- Атомтех: Научно-производственное унитарное предприятие. – 84с.
10. Instructions and technical guidelines on ground-based examination of radiation situation on the contaminated territory: app. by Inter-Branch Commission on Environment Radiation Control at Goskomgydromet, USSR, -M., 1989 .
    Инструкция и методические указания по наземному обследованию радиационной обстановки на загрязненной территории: утв. Межведомственной комиссией по радиационному контролю природной среды при Госкомгидромете СССР. - М., 1989.
11. MI 2143-91 No. 5.06.001.98 Activity of radionuclides in bulk samples. Methods of gamma-spectrometric measurements. Recommendations. State system providing uniformity of measurements. – Intr.1998-06-02. -1991. – p.17.
    МИ 2143-91 № 5.06.001.98 Активность радионуклидов в объемных образцах. Методика выполнения измерений на гамма-спектрометре. Рекомендация. Государственная система обеспечения единства измерений. - Введ.1998-06-02. -1991. - 17с.

12. Nuclear tests in the USSR. Semipalatinsk Test Site / edited by Logachev V.A. – Moscow: Publ. AT, 1997.
Ядерные испытания СССР. Семипалатинский полигон/ под ред. В.А. Логачева. – Москва: Изд AT, 1997.
13. Logachev V.A. Influence of nuclear tests at the Semipalatinsk Test Site on health of local population of Kemerovskaya and Novosibirskaya oblasts // Bulletin of the Center of Public Information on Atomic Energy: Special Publ. – Moscow: TsNIIAtominform, 1996. – No. 12. – pp. 10-11.
Логачев В.А. Влияние ядерных испытаний на Семипалатинском полигоне на состояние здоровья населения Кемеровской и Новосибирской областей / В.А. Логачев // Бюллетень центра общественной информации по атомной энергии: Спецвыпуск. – Москва: ЦНИИатоминформ, 1996. - № 12. – С. 10-11.
14. Logachev V.A. On radiation impact of nuclear tests at the Semipalatinsk Test Site on the population of Tuva Republic // Bulletin of the Center of Public Information on Atomic Energy: Special Publ. – Moscow: TsNIIAtominform, 1998. – No. 12. – p. 56.
Логачев В.А. О радиационном воздействии на население Республики Тувы ядерных испытаний, проведенных на Семипалатинском полигоне / В.А. Логачев // Бюллетень центра общественной информации по атомной энергии. – Москва: ЦНИИатоминформ, 1998. - № 12. – С. 56.
15. Logachev V.A. An analytical survey on the data on impact of nuclear tests at the Semipalatinsk Test Site on health of the population of the Republic of Gorny Altai // Bulletin of the Center of Public Information on Atomic Energy: Special Publ. – Moscow: TsNIIAtominform, 1998. - № 9-10. – p. 39.
Логачев В.А. Аналитический обзор данных о влиянии ядерных испытаний на Семипалатинском полигоне на состояние здоровья население Республики горный Алтай // Бюллетень центра общественной информации по атомной энергии. – Москва: ЦНИИатоминформ, 1998. - № 9-10. – 39с.
16. Saybekov T.S. Atlas. Radiation situation on the territory of the Republic of Kazakhstan in the period from 1954 to 1994. Semipalatinsk oblast. / Saybekov T.S., Abylayev Zh.A. – V. 16. – Almaty: RK Ministry of Ecology and Bioresources, 1997. – p. 400.
Сайбеков Т.С. Атлас. Радиационная обстановка на территории Республики Казахстан с 1954 по 1994 годы. Семипалатинская область /Т.С. Сайбеков, Ж.А. Абылаев. – Т. 16. – Алматы: Министерство экологии и биоресурсов РК, 1997. – 400.
17. "On technology of atmospheric tests", http://www.iss-atom.ru.
18. http://www.maps.google.ru
19. MI 2139-91 No.5.05.008.99. Methodological recommendations.
МИ 2139-91 №5.05.008.99 Методические рекомендации.
20. Instruction on operation of gamma-spectrometer Canberra with software Genie 2000.
21. Сайбеков Т.С., Абылаев Ж.А. Атлас. Радиационная обстановка на территории Республики Казахстан с 1954 по 1994 годы. Алматы: Министер-

ство экологии и биоресурсов РК, 1997 –Т.16, Семипалатинская область. 400 с.
22. Shoykhet Ya.N. Radiation impact of the Semipalatinsk Test site on Altay Kray. Vestnik of scientific program "Semipalatinsk Test Site – Altai", No.1(9), 1996. Shoykhet Ya.N., Loborev V.M., Kiselev V.I., Lagutin A.A., Sudakov V.C.
Шойхет Я.Н. Радиационное воздействие Семипалатинского полигона на Алтайский край. Вестник научной программы «Семипалатинский полигон - Алтай», №1(9), 1996. Шойхет Я.Н., Лоборев В.М., Киселев В.И., Лагутин А.А., Судаков В.В.
23. Scientific-practical journal. Vestnik of scientific program "Semipalatinsk Test Site – Altai", No.1, 1994, pp. 11-12.
Научно-практический журнал. Вестник научной программы «Семипалатинский полигон - Алтай», №1, 1994, 11-12 с.
24. Kiselev V.I. Consequences of radiation impact of nuclear tests on the population of Altai Krai and measures on its social protection. Shoykhet Ya.N., Kolyado I.B., Ziborov A.M. edited by Shoygu S.K.
Киселев В.И. Последствия радиационного воздействия ядерных испытаний на население Алтайского края и меры по его социальной защите. Шойхет Я.Н., Колядо И.Б., Зиборов А.М., Шойхет Я.Н., под редакцией Шойгу С.К.
25. Mikhailov V.N. Nuclear Tests in the USSR. Andryushin I.A., Bogdan V.V., Zelentsov S.A., Il'kayev R.I., Kaurov G.A., Mikhailov V.N., Tsyrkov G.A., Chernyshov A.K., Moscow, 1997.
Михайлов В.Н. Ядерные испытания СССР. Андрюшин И.А., Богдан В.В., Зеленцов С.А., Илькаев Р.И., Кауров Г.А., Михайлов В.Н., Цырков Г.А., Чернышев А.К., Москва, 1997.
26. Report on the ISTC project K-054 for the first year. "Ecological ways of radionuclide migration related to nuclear tests on the Semipalatinsk Test Site", Kurchatov, 1998.
Отчет по проекту К-054 за первый год. «Экологические пути миграции радионуклидов, связанных с ядерными испытаниями на Семипалатинском полигоне», г. Курчатов, 1998 г.
27. Instruction on operation of dosimeter-radiometer Radiagem 2000.
28. Radiation Safety Standards (NRB-99)
Нормы радиационной безопасности (НРБ-99)
29. Materials on the problems of radioecological state of the former STS caused by impact of nuclear tests: final report. Arzamas–16. Moscow, Saint-Petersburg, 1994.
Материалы по вопросам радиоэкологического состояния территории бывшего СИП в результате воздействия значимых ядерных испытаний: окончательный доклад. Арзамас – 16. Москва, Санкт-Петербург, 1994.
30. "Nuclear Tests Banned. What's next?" http://www.nasledie.ru/voenpol/.
«Ядерные испытания под запретом. Что дальше?», http://npc.sarov.ru/issues/coretaming/.
31. "Taming Nuclear Energy", http://npc.sarov.ru/issues/coretaming/.
«Укрощение ядра», http://npc.sarov.ru/issues/coretaming/.

СЕМЕЙ СЫНАҚ ПОЛИГОНЫ «ТӘЖІРИБЕ ДАЛАСЫ» АЛАҢЫНЫҢ РАДИОНУКЛИДТІ ЛАСТАНУ СИПАТЫ МЕН ДЕҢГЕЙЛЕРІ

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«Тәжірибе даласы» нысаны Кеңес Одағының алғашқы сынақ алаңы болып табылады. Бұрын бұл ұлан-байтақ алаңға жүйелі зерттеу жүргізілген жоқ болатын.

Радиациялық ахуалды анықтау үшін және радиациялық-қауіпті нысандарды түгендеу мақсатында «Тәжірибе даласының» барлық аумағы, сондай-ақ ондағы орналасқан П-1, П-2, П2-Г, П-3, П-5 және П-7 техникалық алаңдар аумағы зерттелді. Техникалық алаңдарды зерттеу аса радиациялық-ластанған телімдерді анықтауды, жаяу γ-түсірулерді жүргізуді, техногенді радионуклидтердің алаңдық және тереңдік таралуын зерттеуді қамтыды.

Интегралды радиациялық параметрлер бойынша «Тәжірибе даласының» тек азғантай бөлігі ғана радиациялық-ластанған аумаққа жатуы мүмкін. 0,3 мкЗв/сағ. жоғары ЭДҚ деңгейі бар алаң шамамен 10 км^2, яғни «Тәжірибе даласының» барлық аумағының 3% құрайды.

Ядролық жарылыстардың «эпиорталықтары» ретінде идентификациялануы мүмкін бірнеше телімдер анықталды. Әдеттегідей, эпиорталықтардағы және оларға іргелес аумақтардағы топырақ жасанды радионуклидтер (ЖРН) шоғырлануының жоғары мәндерімен сипатталады. ЖРН радиалды бағыттағы шоғырлануының өзгеруі экспоненциалды сипатқа ие, бұл кезде 300-500 метр арақашықтықта ЖРН шоғырлануыны іс жүзінде аялық деңгейге дейін төмендейді. Сонымен бірге, жалпы заңдылық болған кезде әр эпиорталықтың басқаларынан, бәрінен бұрын, әр түрлі радионуклидтер мен олардың изотоптарының шоғырлануының арақатынасымен ерекшеленетін өзінің «радионуклиті портреті» бар екендігін атап өту қажет. Ластанудың «алаңдық» деп атауға болатын басқа типі бар телімдер анықталды. Әр түрлі ядролық сынақтардан түсулердің суперпозициясы бұл типті телімдердің негізгі болжамды пайда болу механизмі болып табылады. Телімдер техногенді радионуклидтер шоғырлануының ондаған квадрат километрге дейін алаңы бар үлкен аумақта шартты тегіс таралуымен сипатталады.

^{137}Cs және ^{90}Sr бөліну өнімдері үш негізгі: солтүстік-шығыс, оңтүстік-шығыс және оңтүстік-батыс бағытта таралады. Көптеген шоғырлану тікелей ядролық жарылыстардың эпиорталықтарында орналасқан. ^{241}Am және, сол сияқты $^{239+240}$Pu радионуклидтері көптеген мөлшерде барлық техникалық алаңдардың, әсіресе П-2, П-7 эпиорталық аймақтарында және оның шегінен тыс радиоактивті түсулердің созылған іздері түрінде бар. Бөлінетін заттектер мен бөліну өнімдерінен басқа, эпиорталықтарда нейтронды активация өнімдері: Co^{60}, Eu$^{152, 154, 155}$ шоғырланған, бұл, негізінен, техникалық алаңдар шегінен тыс шықпайды.

Түйін сөздер: Семей сынақ полигоны, тәжірибе даласы, радиациялық ахуал, техногенді нысандар, техногенді радионуклидтер, цезий, стронций, америций, плутоний, кобальт, европий, алаңдық зерттеу, радионуклидті ластану, түгендеу, радиациялық-қауіпті нысан.

ХАРАКТЕР И УРОВНИ РАДИОНУКЛИДНОГО ЗАГРЯЗНЕНИЯ ПЛОЩАДКИ «ОПЫТНОЕ ПОЛЕ» СЕМИПАЛАТИНСКОГО ИСПЫТАТЕЛЬНОГО ПОЛИГОНА

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Объект «Опытное поле» является первой испытательной площадкой ядерного оружия Советского Союза. Систематических обследований этой обширной территории ранее не проводилось.

Для выяснения радиационной обстановки и с целью инвентаризации радиационно-опасных объектов была исследована территория всего «Опытного поля», а также технических площадок П-1, П-2, П2-Г, П-3, П-5 и П-7, располагающихся на нем. Исследование технических площадок включало в себя выявление наиболее радиационно-загрязненных участков, проведение пешеходных γ-съемок, исследование площадного и глубинного распределения техногенных радионуклидов.

По интегральным радиационным параметрам только небольшая часть «Опытного поля» может быть отнесена к радиационно-загрязненной территории. Площадь с уровнем МЭД выше 0,24 мкЗв/ч составляет около 11 км^2, то есть 3% от всей территории «Опытного поля».

Выявлены несколько участков, которые могут быть идентифицированы как «эпицентры» ядерных взрывов. Как правило, почва на эпицентрах и территориях, прилегающих к ним, характеризуется высокими значениями концентрации искусственных радионуклидов (ИРН). Изменение концентрации ИРН в радиальном направлении носит экспоненциальный характер, при этом на расстоянии 300-500 метров концентрация ИРН снижается практически до фоновых уровней. Вместе с тем, следует отметить, что при наличии общих закономерностей, каждый эпицентр имеет свой «радионуклидный портрет», отличающийся от других, прежде всего, соотношением концентрации различных радионуклидов и их изотопов. Выделены участки с другим типом загрязнения, которое можно назвать «площадным». Основным возможным механизмом возникновения участков этого типа является суперпозиция выпадений от различных ядерных испытаний. Участки характеризуются условно равномерным распределением концентрации техногенных радионуклидов на больших территориях площадью до десятков квадратных километров.

Продукты деления ^{137}Cs и ^{90}Sr распространяются в трех основных направлениях: северо-восточном, юго-восточном и юго-западном. Наибольшая концентрация находится непосредственно на эпицентрах ядерных взрывов. Радионуклиды ^{241}Am и, следовательно, $^{239+240}$Pu в значительной мере присутствуют в эпицентральных зонах всех технических площадок, особенно на П-2, П-7 и за их пределами в виде протяженных следов радиоактивных выпадений. Помимо делящихся веществ и продуктов деления, в эпицентрах сконцентрированы продукты нейтронной активации: Co^{60}, Eu$^{152, 154, 155}$, которые, в основном, не выходят за пределы технических площадок.

Ключевые слова: Семипалатинский испытательный полигон, опытное поле, радиационная обстановка, техногенные объекты, техногенные радионуклиды, цезий, стронций, америций, плутоний, кобальт, европий, площадное обследование, радионуклидное загрязнение, инвентаризация, радиационно-опасный объект.

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RADIOECOLOGICAL CONDITIONS AT THE WESTERN PART OF STS TERRITORY

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The paper presents the results of radioecological investigations of western part of the Semipalatinsk Test Site (STS) located on the territory of Karaganda oblast on the area of 560 km^2. The present-day radioecological state of the environment components – soils, water objects, air, vegetation and animal world have been studied. The average concentration of natural radionuclides in soils of the studied area is typical of Kazakhstani soils; no geochemical anomalies were discovered. Presence of artificial radionuclides in the environmental objects of western part of the STS territory is mainly caused by global radioactive fallouts. As a whole, radionuclides ^{137}Cs and ^{90}Sr are rather uniformly distributed over the area. An analysis of ^{241}Am Areal distribution revealed the areas with increased concentrations of specific activity. Maximal values of specific activities of radionuclides ^{137}Cs and ^{90}Sr were found to be below the levels characterizing ecological state of the area as "relatively satisfactory ecological state". In terms of $^{239+240}$Pu concentration, the state of surveyed areas is classified as "relatively satisfactory ecological state". Radionuclide concentrations in vegetation, water and air as well as expected concentrations in foodstuffs of vegetal and animal origin are much lower than the permissible levels. Based on the data on radionuclide concentrations in the environmental objects and foodstuffs, radiation exposure of local people was estimated. In case of the "worst" scenario a farmer living on subsistence farming in the contaminated area, will get the annual expected effective dose not exceeding 0.3 mSv, which is below the intervention level according to the Radiation Safety Standards. Therefore the results of complex investigation, taking into account the acting requirements of the RK legislative base, show the all the studied area can be used for commercial activities without any limitations.

These investigations were aimed at further transfer of the studied lands into economic use.

Keywords: nuclear tests, radioecology, radioactive contamination, radionuclides, vegetation cover, objects of water use, behavior scenario, radiation exposure.

INTRODUCTION

One of the main objectives of investigations carried out on the STS is gradual land transfer into economic use. Lands can be transferred into economic use only after complex ecological investigations and rehabilitation measures on the most hazardous areas of radioactive contamination. Such works have already been done in the "northern" part of the STS territory [1].

At the moment of the STS closure on the territory of Karaganda oblast different types of agricultural works were being done, mainly, pasture sheep breeding which is confirmed by the presence of winter huts, now not inhabited, and odds and ends of a rather well-developed infrastructure (road network, power transmission lines, network of boreholes and wells). After collapse of the USSR the winter huts were abandoned, and people moved to larger villages beyond the STS.

Different types of radioecological investigations on the territory of Karaganda oblast were carried out earlier. In order to study the influence of nuclear tests on the territory of Karaganda oblast a program of radioecological survey was developed and started in 1995 (Center-Geosurvey, JSC, Ecoexpert, LLP). The investigations in the framework of the program were continued in 2001–2002. The works were fulfilled by the Institute of Radiation Safety and Ecology (IRSE NNC RK) [2].

In 2009–2010 the IRSE carried out complex ecological investigation of "western" part of the STS territory over the area of 560 km^2. This research continued earlier investigations of the test site. The subjects of investigations were the environmental objects: soil-vegetation cover, water, air and animals. The STS territory where the investigations were carried out is denoted by a blue line on the map (Figure 1).

1. TESTS AT THE STS AS PRIMARY SOURCES OF RADIOACTIVE CONTAMINATION OF THE STUDIED AREA

No tests with nuclear materials were made directly on the territory of the studied area. The test site most closely located to the studied area is the "4" site (less than 4 km away), it is the site where tests of warfare radioactive agents were made; Sary-Uzen (nuclear tests in boreholes) and "Experimental field" (also known as *Opytnoye pole*) (atmospheric and ground tests) are 18 km away. The other test sites are located more than 50 km away (Figure 1), and it is unlikely that they may influence the radiological environment in the studied area.

An analysis of available data shows that radiation environment of the studied area could be formed under the action of the following factors: atmospheric nuclear tests and model tests (hydronuclear and hydrodynamic) on the "Experimental field" site as well as tests of warfare radioactive agents on the "4" site. A considerable influence on the radiation environment in the "western" area could be exerted by excavation explosions made in boreholes No. 1003, 101, 125 on the test site Sary-Uzen. However, a detailed studying of traces of radioactive fallouts formed in the tests shows that the traces moved in the opposite direction from the studied area.

1.1. Atmospheric tests on the "Experimental field" site

In the period from 1949 to 1962, 30 ground and 80 atmospheric nuclear tests were made on technical sites P-1, P-2, P-3, P-5 and P-7. In the period from 1958 to 1989, 85 hydronuclear tests including 2 atmospheric, 15 underground and 68 ground tests were made on the test site. All tests, to some extent, caused radioactive contamination of the territory of the test site and adjacent areas.

Ground and near-ground nuclear tests. Open publications [3-7] contain information about the number, time, power and other characteristics of nuclear tests such as the average wind direction and fallouts beyond the test site, trajectories of radioactive clouds from the boundary of the test site and traces of radioactive fallouts. Different literature sources present different information on the above characteristics. Our analysis of the above information shows that 3 ground tests made on 05.10.54 (4 kilotons), 02.08.55 (12 kilotons) and 25.03.56 (5.5 kilotons) could have caused radioactive contamination of the studied area. Based on

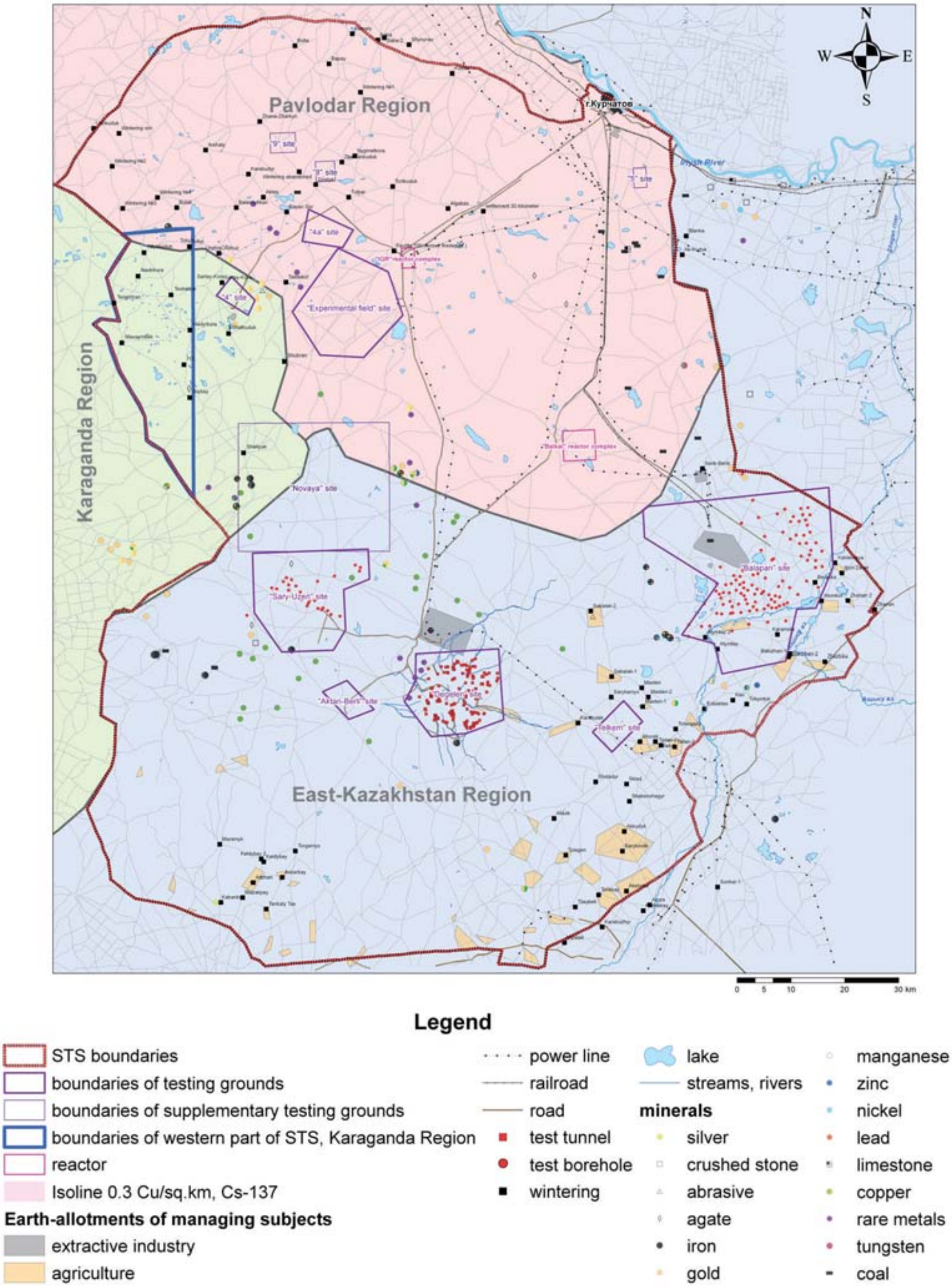
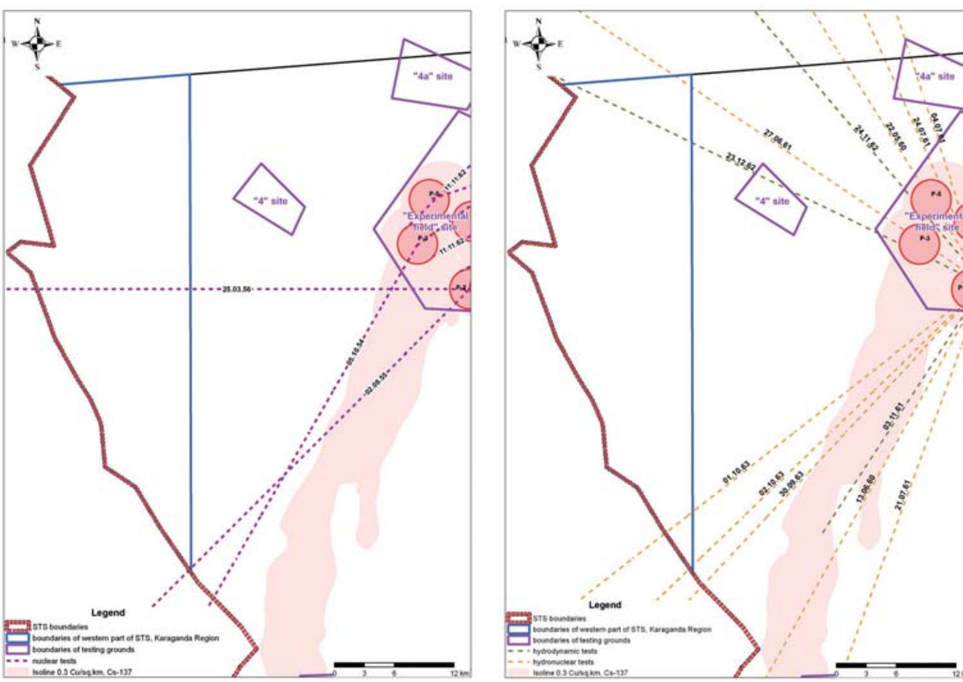


Figure 1. General map of the area.

the above information we reconstructed trajectories of radioactive fallouts from the ground nuclear tests (Figure 2a).

The radioactive clouds from the three nuclear tests moved from their test sites in western and southwestern directions. Based on the results of earlier radiological surveys on the STS territory the data witnessing increased radioactive contamination of the soil cover within the traces of radioactive fallouts from the above nuclear tests were gathered. No detailed information about specific features of the tests and formation of traces of radioactive fallouts is available.

The contamination from the tests could have been formed by the stripes of radioactive contamination expanding from the epicenter of nuclear explosion and reaching 10 km in width on the boundary of the test site.



a) b)

Figure 2. Traces of radioactive fallouts from a) ground and b) hydro-nuclear and hydrodynamic tests in the western part of the test site

1.2. Model experiments (hydro-nuclear and hydrodynamic)

Hydro-nuclear tests. In the period from 1960 to 1065, over 40 hydro-nuclear tests were made on the P-2G site (located on the territory of P-2, P-7 sites). The total alpha-activity of plutonium dispersed in all hydro-nuclear experiments amounted to about 800-900 Ci, which could have caused radioactive contamination of the area around the experimental site [8].

For potential possibility of plutonium contamination of the studied area the axes of traces formed by the tests had to lie in the sector 226^{o} – 307^{o} (from southwest to northwest direction). According to the available information [7] only 2 tests of 24, in which plutonium was dispersed, had azimuth directions of trace axes 226^{o} and 232^{o}, for them the lengths of zones with plutonium area contamination of 0.1 Ci/km^2 could have reached 30.5 and 34.4 km, respectively, and the lengths of zones with plutonium contamination of 2.25 × 10^{-2} Ci/km^2 could have reached 92 and 105 km. These characteristics show that most probably the two tests made on 01.10.1963 and 02.10.1963 (Figure 2b) with releases of 54.5 and 50.5 Ci of plutonium could contribute to radioactive contamination of the southern part with plutonium isotopes. In estimating sources of radiation contamination we considered information about one more test described in [7]. In the experiment made on 27.06.1961 the direction of the cloud – 304^0 was given. The experiment could have also caused contamination of the studied territory with plutonium isotopes.

Hydrodynamic tests. Explosive tests with nuclear charges where nuclear energy is not released refer to the category of hydrodynamic tests, they do not refer to nuclear tests except the cases when such a result was registered in the specially planned nuclear test.

Hydrodynamic tests were made on the test sites P-2 and P-7. The test sites were located at a distance of about 28km from the boundary of the studied area. In the period from 1954 to 1962, 5 tests were made as a result of which 1,000 Ci of plutonium were released into the atmosphere. To estimate probabilities of area contamination the same sector was considered (from 226^{o} to 307^{o}). According to the data [7] in one of the five tests (23.12.1962) the azimuth direction of the trace axis was 296^{o}, in this case the length of zones with plutonium area contamination of 0.1Ci/km^2 could have reached 68 km, and zones with plutonium area contamination of 2.25 × 10^{-2} Ci/km^2 could have stretched for over 100km (Figure 2b). Therefore the test could be also considered as a source of contamination of the studied area with plutonium.

At the present time radioactively contaminated areas on the "Experimental field" site can be also sources contaminating the studied area by migration processes, mainly, by wind transfer of radioactively contaminated soil particles. The areas with high levels of radioactive contamination are mainly located within the sites where ground nuclear tests and model experiments (P-1, P-2, P-3, P-5, P-7) were made. Maximal values of radiation dose rate and, hence, maximal levels of radionuclide contamination are located directly near the hollows formed by nuclear explosions. The values of specific activity of artificial radionuclides in soil are presented in the table (Table 1). Radioactive contamination of soil on these areas is comparable with solid radioactive wastes (in some spots – with medium-active radioactive wastes).

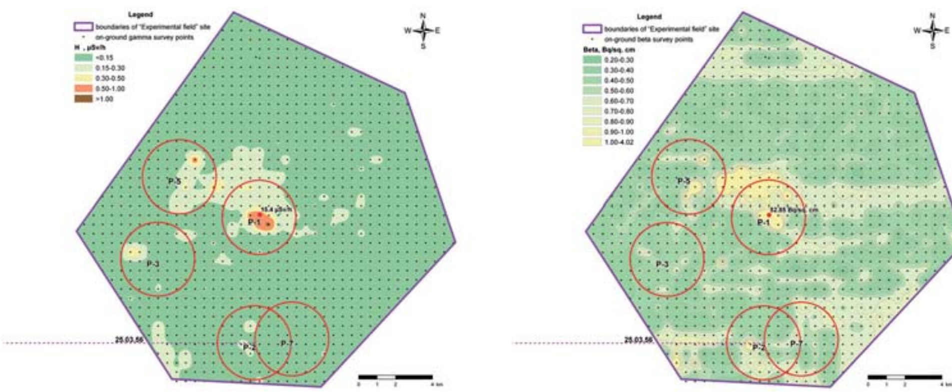
Table 1.

Specific activity of radionuclides in soil near technical areas of the test "Experimental field" site

Site	Specific activity, Bq/kg							
	^{60}Co	^{90}Sr	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{241}Am	$^{239+240}$Pu
P-1	n*10^2	n*10^4	n*10^3	n*10^4	n*10^1	n*10^1	n*10^2	n*10^3
P-2	n*10^1	n*10^3	n*10^4	n*10^3	-	-	n*10^5	n*10^4
P-3	n*10^2	n*10^3	n*10^3	n*10^4	n*10^2	-	n*10^5	n*10^5
P-5	n*10^2	n*10^6	n*10^5	n*10^4	n*10^2	n*10^2	n*10^5	n*10^7
P-7	n*10^2	n*10^4	n*10^4	n*10^3	n*10^1	n*10^1	n*10^3	not measured

As the distance from the epicenters increases, the EDR decreases, and at a distance of 1-2km it is equal to the background values for the area of about 0.10-0.15 μSv/h. Thus, the radioactive contamination from nuclear tests on the "Experimental field" site is concentrated in the vicinity of epicenters forming traces of short-range radioactive fallouts, and decreases to the background levels with increase in the distance from the epicenter (Figure 3a).

The results of investigation of the test "Experimental field" site enabled to detect areas of radioactive contamination identified as traces of short-range radioactive fallouts. Based on the assessment of Sr^{90} concentration determined by X-ray technique, the map-scheme of contamination of the test "Experimental field" site by β-active radionuclides was constructed (Figure 3b).



a) b)

Figure 3. A map-scheme of EDR values (a) and flow density of β-particles (b) on the "Experimental field" site.

Analyzing dose rates and area β-activity on the test site one can suppose that the area of radioactive contamination located to the west from the sites P-2, P-7 was formed as a result of nuclear test made on 25.03.56. The figure shows that the trace of radioactive fallouts was directed to the western part of the test site.

1.3. Tests of warfare radioactive agents on the "4" site

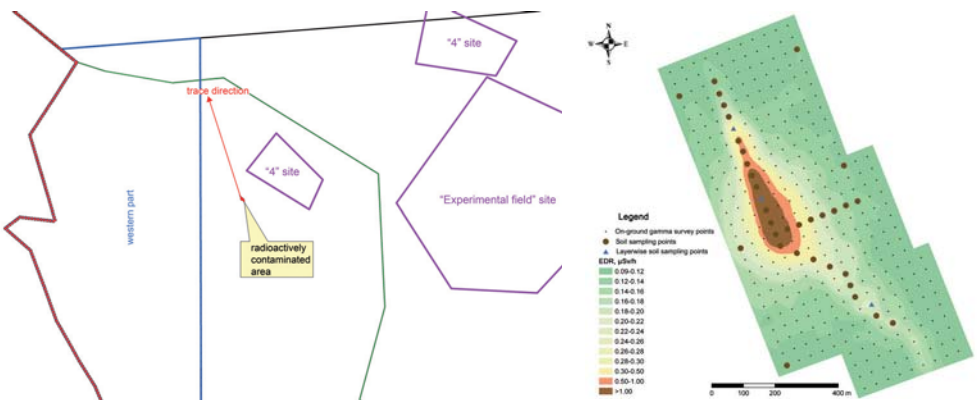
Nuclear explosions were not the only type of tests made on the STS territory. In the period between 1954 and 1957 tests of radiological weapons equipped with warfare radioactive agents (WRA) [9] were made.

The basic element of such weapons of mass destruction as WRA was liquid or powder radioactive substances. Such radioactive substances were mainly obtained from wastes of radiochemical industry. In the STS tests the radioactive substance was a product (receipt 904) with specific activity ranging from tenths of Curie to several Curies per liter. The total activity of dispersed substance containing long-lived radionuclides could have been as high as 10,000-12,000 Ci.

The WRA tests were made on the STS by blasting of some units of ammunition, bombing from the plane IL-28, mortar shells or pouring-out aviation devices. As it was very difficult to deactivate the equipment, all the equipment used in the WRA tests (capacities, pipes, pumps, etc.) was disposed under the 5m soil layer. The places of disposal are not known.

The WRA tests were made on two sites "4" and "4a", in the northeastern part of the STS (Figure 2). One of the sites, "4a", is located less than 4 km away from the studied area. As a result of the WRA tests local zones of radioactive contamination, mainly within the test area, were formed. Those tests could have also contributed to the radioactive contamination of the studied territory.

Previous investigations detected 6 radioactively contaminated areas on the "4" site and beyond its boundaries. On the area closely located to the western territory is a radioactively contaminated zone (Figure 4,a) with maximal EDR value on the ground surface of about 45 µSv/h and β-flux density above the detection threshold of used measuring devices (4,500 part/min*cm^2). Figure 4b shows the scheme of EDR distribution on the contaminated area beyond the site "4".



a) b)

Figure 4. A scheme of distribution of radioactive contamination (a) and EDR on the contaminated area (b)

The samples taken from the area were subjected to gamma- and beta-spectrometry analysis to identify natural and artificial radionuclides and ^{90}Sr. Maximal values of radionuclide specific activities in the measured samples were ^{60}Co – 9*10^1, ^{152}Eu –5*10^1, ^{241}Am – 4.3*10^3, ^{90}Sr – 4.8*10^6, ^{154}Eu – 1.5*10^3, $^{239+340}$Pu – 4.7*10^4, ^{137}Cs – 1.4*10^3, ^{155}Eu – 1.5*10^3Bq/kg. By the level of radioactive contamination the soil in the studied zone, it can be compared with radioactive wastes. This zone can affect the radioactive level of the STS western part.

Nowadays, in addition to natural factors (wind transfer) there are anthropogenic factors which can form secondary radioactive contamination of the studied area. Such factors include earthworks related with collection of scrap metals in the areas of nuclear tests and its removal beyond the STS territory and agricultural works (cattle pasturing and hay making) on radioactively contaminated areas.

It is possible to estimate transfer of radioactive substances during gathering and removal of scrap metal. As a preventive measure reducing the level of radioactive contamination of areas located near test site it is necessary to prohibit unauthorized access of local people and domestic animals.

2. COMPLEX INVESTIGATIONS OF ENVIRONMENTAL CONDITIONS

Based on the data obtained in the survey of potential sources and earlier researches, the complex radioecological survey was carried out in a few stages. The following strategy was used in the survey: preliminary estimation of radionuclide distribution in the soil cover by the results of radionuclide analysis of soil samples taken with a 1x1 km net, determination of soil and vegetation contours, search for and examination of all water sources including water sampling and radionuclide analysis of samples. Then in the areas with increased radionuclide concentration in soil additional sampling was made with a smaller net. More detailed investigations were also carried out within identified soil-vegetation contours. In the area of typical soil contours the samples of surface soil layer were taken, trenches were made and to study radionuclide distribution in depth layered samples were taken. The results of deciphering of satellite-borne images and field reconnaissance exploration determined location of all water objects on the studied territory. To estimate radionuclide concentration in air the aerosol samples were taken in the places where people had lived (in abandoned winter-camps).

All in all, 911 soil samples were taken (including 146 layered soil samples), 22 vegetation samples, 27 water and 5 air samples. Laboratory examination of environmental samples on the presence of natural and artificial gamma-emitting radionuclides included preliminary sample preparation and measurement of prepared samples on gamma-spectrometer.

Laboratory analyses of environmental samples for presence of natural and artificial gamma-emitting radionuclides ^{90}Sr and $^{239+240}Pu$ were made employing radiochemical techniques [10, 11]. The scope of the laboratory analyses is presented in Table 2.

Table 2.

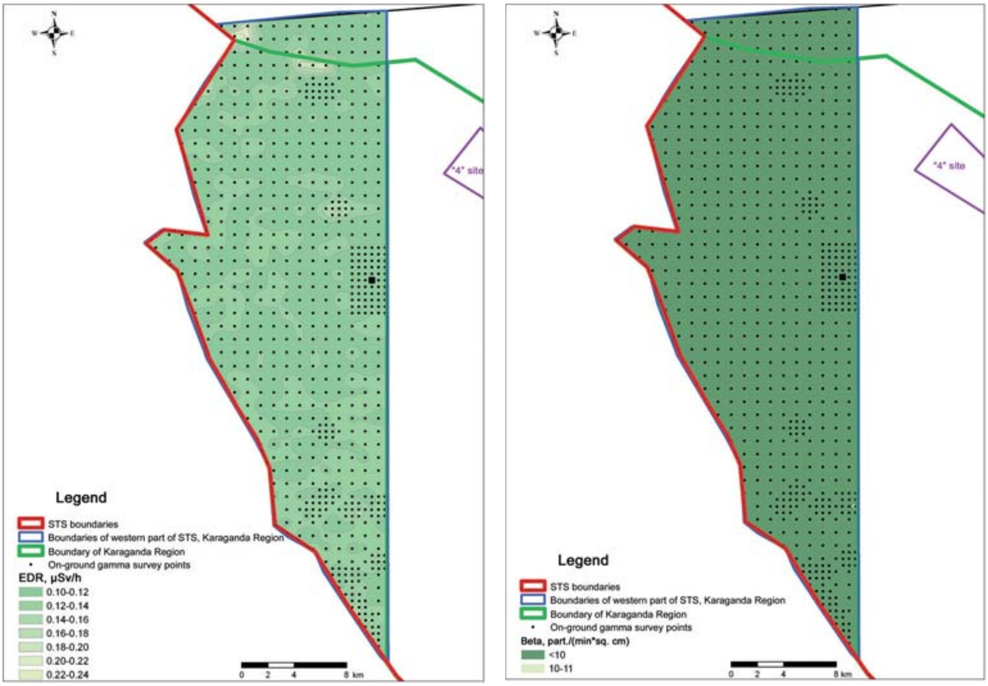
Laboratory analyses

Sample type	Total number of samples	Number of analyzed samples				
		^{90}Sr	^{137}Cs	^{238}Pu	$^{239+240}Pu$	^{241}Am
soil	765	133	765	133	146	765
vegetation	22	22	22	-	14	22
water	27	27	27	-	24	1
air	5	5	5	-	5	5

The methods of environmental sampling and laboratory analyses are described in details in the "Materials of complex survey of STS "northern" areas" [1].

2.1. Distribution of integral parameters

In the sampling points EDR had values ranging from 0.1 to 0.24 µSv/h on the ground surface and from 0.1 to 0.40 µSv/h at a height of 1m. All values of β-flux density were below the detection limit of used measurement devices (10 part/(min*cm^2)) except two points where the β-flux density was 11 part/(min*cm^2).



a) b)

Figure 5. EDR (a) and β-flux density (b) distributions over the studied area

2.2. Areal distribution of radionuclides

2.2.1 Areal distribution of natural radionuclides

The main component of the radiation background on the studied area is caused by natural radionuclides formed by the products of uranium and thorium decay, and potassium (^{40}K). Of natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra were identified. Their specific activity was determined in 765 samples taken from the 0-5 cm surface horizon during area survey of the territory. Average concentrations of the main natural radionuclides in soil are presented in Table 3.

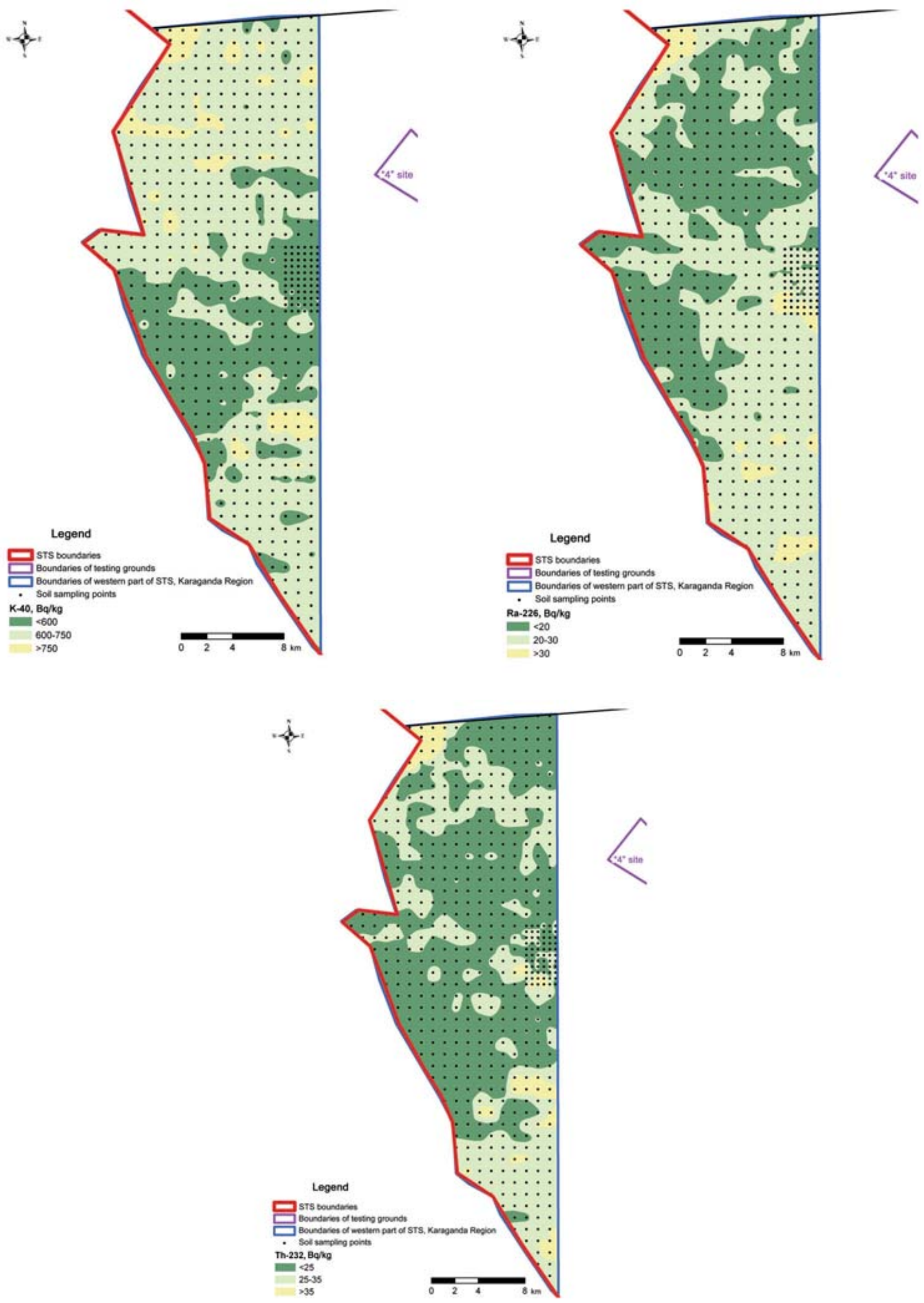


Figure 6. Areal distribution of specific activity of ^{40}K, ^{226}Ra and ^{232}Th in soils of the STS western part (by the results of the 2009–2010 investigations)

Table 3.

Average concentrations of the main dose-forming natural radionuclides in soil

Natural radionuclides, Bq/kg			
^{40}K	**Ряд ^{235}U**	**^{238}U series**	**^{232}Th series**
629 ± 40	0.9 ± 0.3	23 ± 2	26 ± 3

The results of survey were used to construct maps of Areal distribution of ^{40}K, ^{226}Ra and^{232}Th (Figure 6).

Comparing the distribution of specific activity of ^{40}K, ^{226}Ra and ^{232}Th, the scheme of soil cover and topographic map of the area one can assume that the distribution of radionuclides is closely correlated with the landscape of the area. Maximal values of specific activities of natural radionuclides are registered in the relief elevations and rock outcrops. Table 4 gives maximal, minimal and average values of specific activities of natural radionuclides in soils of the Republic of Kazakhstan [12].

Table 4.

Activity of natural radionuclides in Kazakhstani soils

Measurement limits	**Specific activity, Bq/kg**		
	^{40}K	**^{226}Ra (^{238}U)**	**^{232}Th**
Minimal values	100	12	10
Maximal values	1200	120	220
Average	300	37	60
Note: it is assumed that in undisturbed soils uranium and thorium are in radioactive equilibrium, and specific activities of uranium and radium are equal			

2.2.2. Areal distribution of artificial radionuclides

It should be noted that no samples analyzed in gamma-spectrometer contained any other artificial radionuclides besides ^{137}Cs and ^{241}Am, the limits of detection of such radionuclides as ^{60}Co and ^{152}Eu were about 0.5 and 1.0 Bq/kg, respectively.

Character of ^{137}Cs contamination of the area under investigation

By the results of investigations the map of Areal distribution of ^{137}Cs specific activity in the soil cover was made (Figure 7). The total number of studied samples was 765. The values of specific activity ranged from 1 to 63 Bq/kg with the average value of 18 Bq/kg, the total number of points with maximal values (more than 60 Bq/kg) was less than 0.3%. In the histogram (Figure 8) the distribution of frequencies of occurrence of points with certain specific activities is close to logarithmically normal distribution.

The average value of ^{137}Cs specific activity in the area (18 Bq/kg) does not exceed the background of global fallouts for this radionuclide equal to 30 Bq/kg.

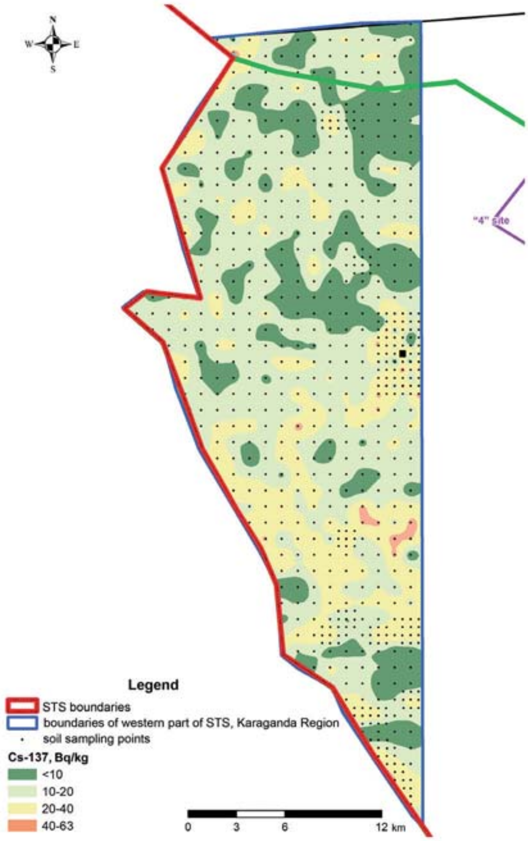


Figure 7. Areal distribution of ^{137}Cs specific activity in soils of the western part of the STS territory (by the results of the 2009-2010 investigations)

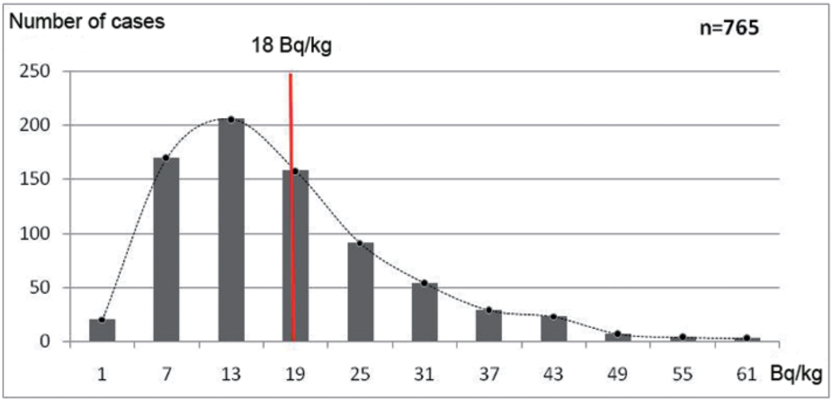


Figure 8. Histogram of occurrence frequencies for ^{137}Cs specific activities in soil

Character of ^{90}Sr contamination of the area under investigation

^{90}Sr concentration was measured by two methods: first, the samples were analyzed on the beta-spectrometer "Progress", in more detailed investigations radiochemical extraction was used. No measurements on the beta-spectrometer "Progress" gave values exceeding the detection threshold (about 100 Bq/kg).

Figure 9 shows the histogram of log-normal distribution of frequencies of occurrence of points with certain ^{90}Sr specific activities.

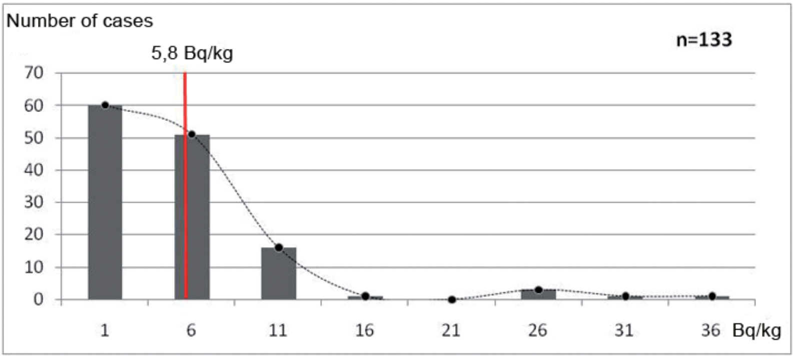


Figure 9. Histogram of ^{90}Sr concentration distribution in soils

The average value of ^{90}Sr specific activity equal to 5 Bq/kg (Table 5) does not exceed the background of global fallouts, equal to 30 Bq/kg for this radionuclide. By the results of investigations the map of ^{90}Sr Areal distribution was made (Figure 11a).

Character of ^{241}Am contamination of the area under investigation

By the results of investigations the map of Areal distribution of ^{241}Am specific activity was made (Figure 11b). It was rather difficult to estimate ^{241}Am specific activity on the studied area as in most samples ^{241}Am concentration was below the detection level (minimal detected activity) of used techniques and equipment (about 50% of all results). A complete ignorance of such values would have given considerably higher results. Therefore in estimating the average value the values of ^{241}Am specific activity were taken equal to the detection limit. Thus, the ^{241}Am "average" specific activity was an upper estimate and was equal to 1.1 Bq/kg (Figure 10).

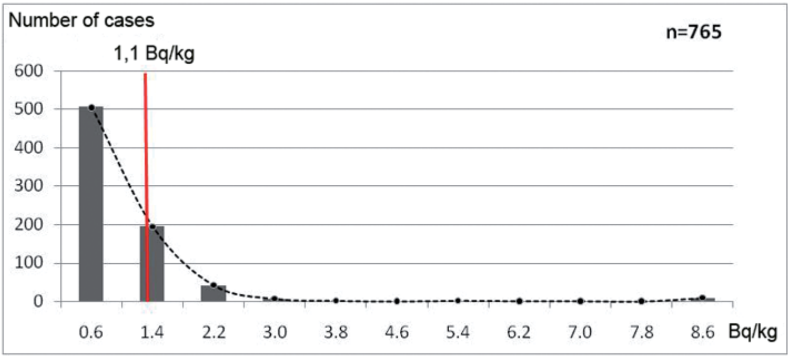
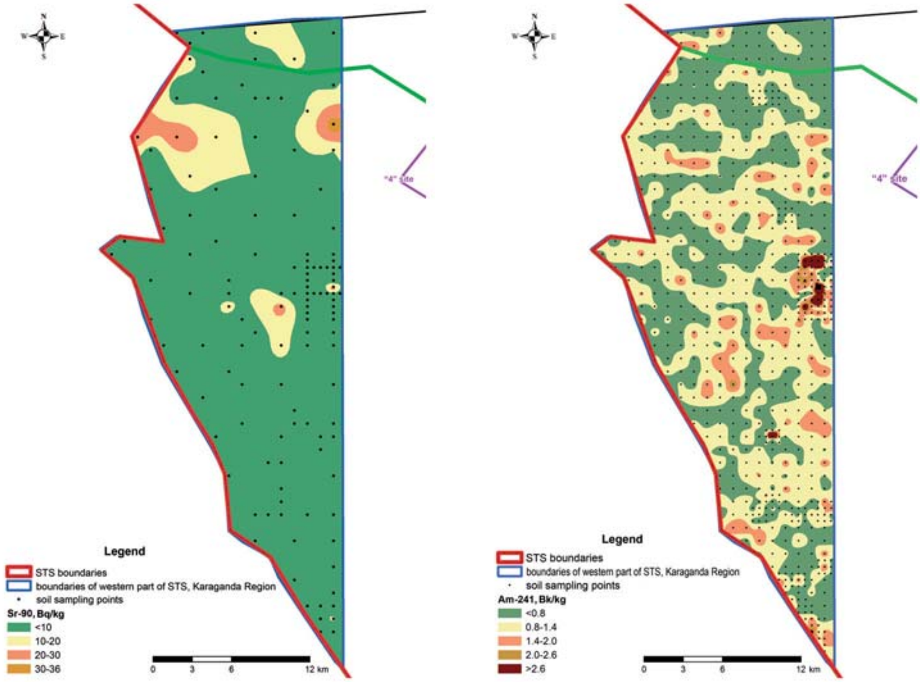


Figure 10. Histogram of occurrence frequencies for ^{241}Am specific activities in soil

The array of ^{241}Am data has dropouts, which can be analyzed as a separate general group characterizing zones with increased concentrations of the radionuclide in soil.



a) b)

Figure 11. ^{90}Sr (a) and ^{241}Am (b) concentrations in soils of the western part of the STS territory (by the results of the 2009-2010 investigations)

Character of $^{239+240}$Pu contamination of the area under investigation

Taking into account labor-consuming procedure of the traditional method of $^{239+240}$Pu identification (alpha-spectrometry with preliminary radiochemical extraction) this investigation of the type of area contamination with plutonium isotopes methodologically focuses on finding correlation between ^{241}Am and plutonium. Such approach is rather widely used and is justified, especially in case of one source of contamination.

By the results of investigations the graph of dependence of $^{239+240}$Pu specific activity on ^{241}Am specific activity was constructed (Figure 12). To determine the ratio of $^{239+240}$Pu / ^{241}Am specific activities a special preparation of soil samples (the procedure included several grinding stages, where the grinding quality was controlled by the ^{241}Am content in the aliquot samples) was used. The value of ^{241}Am specific activity was determined as the average of three measurements.

The average value of the ratio of specific activities $^{239+240}$Pu / ^{241}Am at the intermediate state turned out to be equal to 5.9, which is rather close to the expected value, the correlation coefficient was equal to 0.56 (the total number of samples was 98). As the number of laboratory analyses increased, the average value went down to 5.4. However, in further calculations of dose rates we used the average value of 5.9 as a conservative decision.

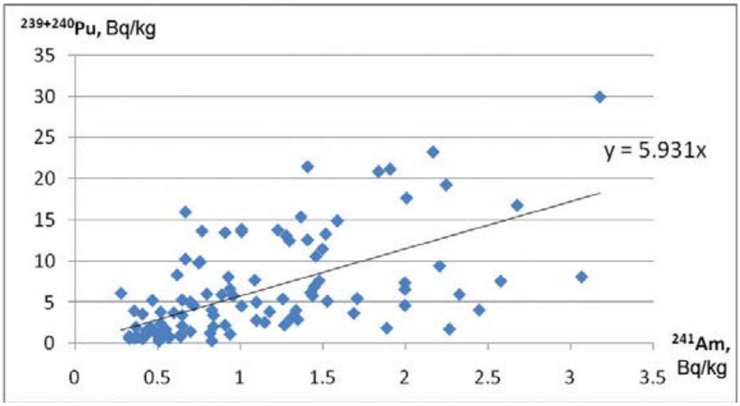


Figure 12. Dependence of $^{239+240}Pu$ specific activity on ^{241}Am specific activity in soil samples

Therefore, the character of contamination with plutonium isotopes does not differ from the character of americium contamination, with the average value of $^{239+240}Pu$ specific activity equal to 6.5 Bq/kg. In 9 spots with increased plutonium concentration samples with a 500x500m net were taken. By the results of measurements the map of $^{239+240}Pu$ point distribution was made (Figure 13).

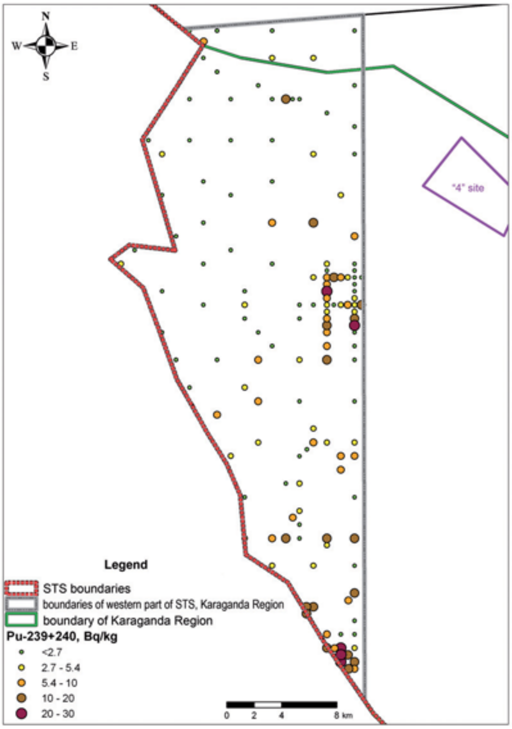


Figure 13. Distribution of $^{239+240}Pu$ specific activity in soils (by the results of the 2009-2010 investigations)

The analysis of the results showed that determination of ^{238}Pu, especially at low concentrations, has a systematic additive error which caused overestimation of the results by 0.24 Bq/kg, which is caused either by insufficient cleaning of alpha-active isotopes of natural origin or by the presence of global ^{238}Pu. The graph of the ratio of ^{238}Pu / $^{239+240}Pu$ specific activities is shown in Figure 14.

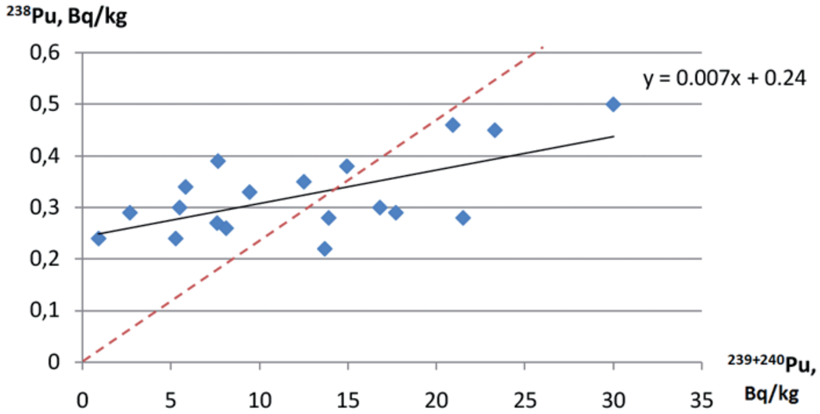


Figure 14. The ratio of ^{238}Pu and $^{239+240}Pu$ specific activities in soil samples

Therefore the average ratio of ^{238}Pu / $^{239+240}Pu$ is 0.007, the average value of ^{238}Pu specific activity is 0.05 Bq/kg, in calculations of dose rates for convenience the value 0.1 Bq/kg is used. For ^{241}Pu the calculated ^{241}Pu / $^{239+240}Pu$ ratio equal to 0.75 is used [1].

Character of contamination of the studied area with other radionuclides

Concentration of such radionuclides as ^{151}Sm and ^{99}Tc, which was not determined experimentally, but the presence of which was expected, was determined by theoretical calculations on the base of average values of ^{137}Cs specific activity and ratios of these isotopes. Based on the ratios of radionuclides produced in the decay, the following values of average specific activity were used in calculations: 1.4 Bq/kg for ^{151}Sm and 0.3 Bq/kg for ^{99}Tc.

The average values of specific activity of artificial radionuclides on the considered territory can be presented as a table to be used in further calculations (Table 5).

Table 5.

Average concentration of artificial radionuclides in the western part of the STS territory

^{137}Cs	^{90}Sr	^{241}Pu	^{238}Pu	^{241}Am	$^{239+240}Pu$	^{99}Tc	^{151}Sm
18	6	3.1	0.1	1.1	6.5	0.3	1.4

2.2.3. Zoning of the territory by areal distribution of the radionuclides

In order to reveal zones with concentrations of specific activity of artificial radionuclides exceeding the average values specified for the considered area, we chose the method of constructing graphs of ^{137}Cs and ^{241}Am concentrations along profiles.

From the results of measurements the data long the profiles perpendicular to the expected traces of radioactive fallouts were chosen. The scheme of profiles is shown in Figure 15. For each profile the distributions graphs for ^{137}Cs and ^{241}Am specific activities were constructed.

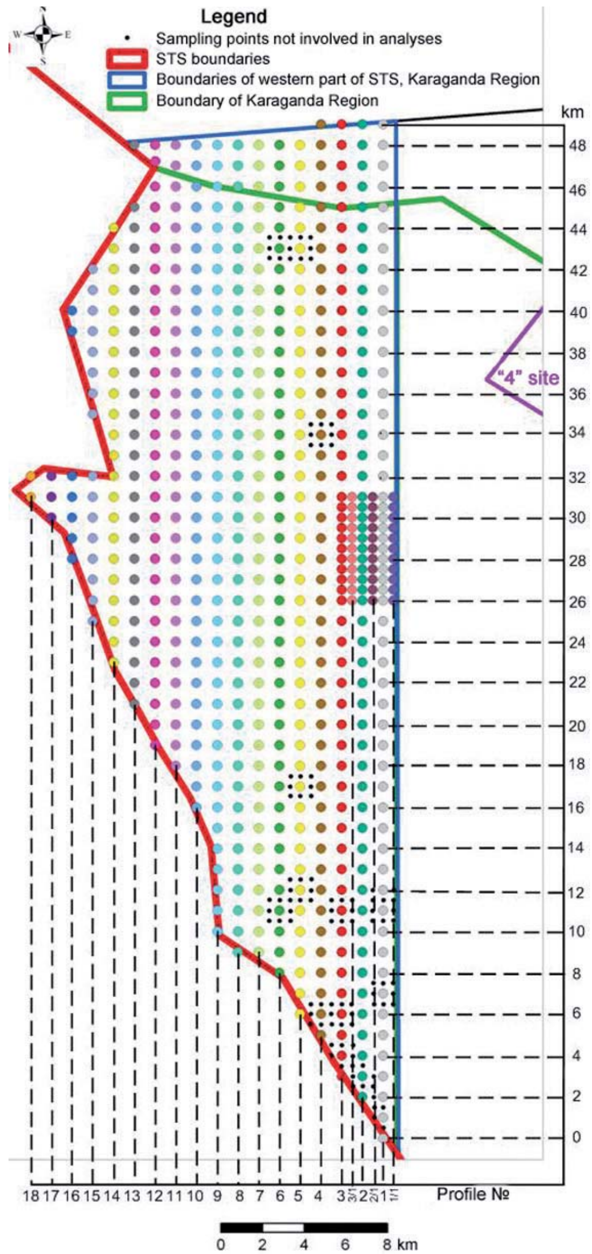
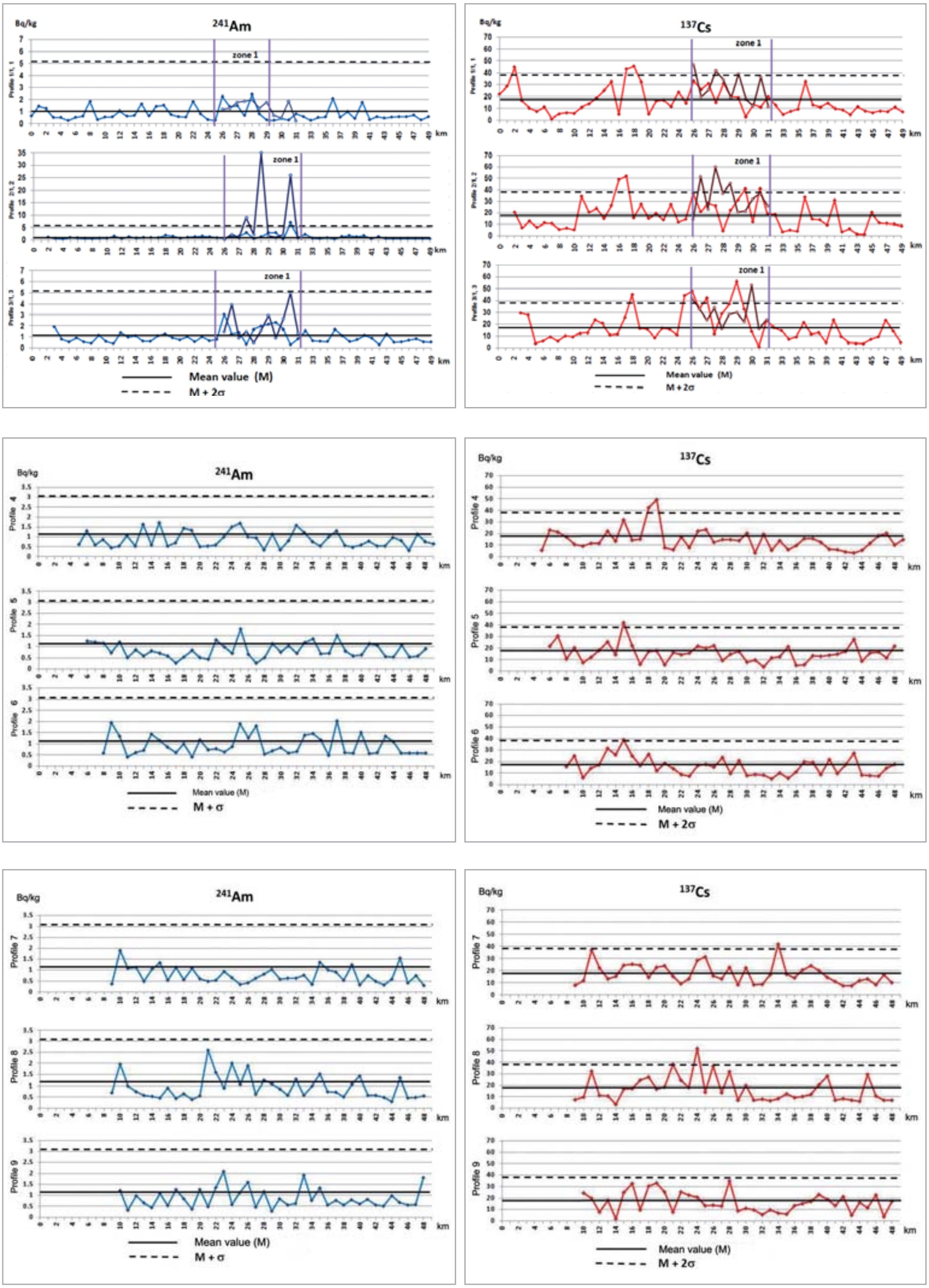


Figure 15. Location of the profiles

Figure 16 shows the graphs of ^{137}Cs and ^{241}Am specific activity in soil for 14 main profiles.



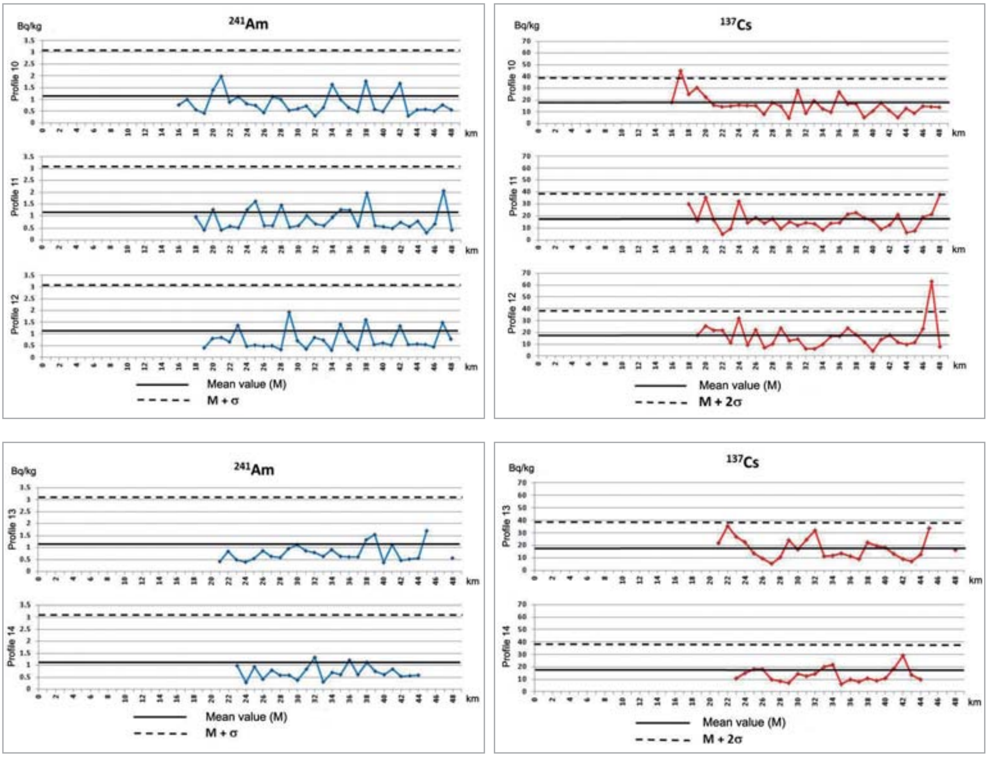


Figure 16. Graphs of ^{241}Am and ^{137}Cs specific activity in soil along the profiles

The distributions of ^{137}Cs and ^{241}Am specific activities have the same zone with increased concentration (Figure 17). In zoning, a special attention was paid to the correspondence between zones with increased concentrations and zones of possible passage of radioactive fallouts detected in the earlier data. The area under investigation contains a trace of the radioactive cloud of the 1956 nuclear explosion, which could give increased values of specific activity.

Average values of specific activity of artificial radionuclides to be further used in calculations of dose rates have been calculated for the zone (Table 6).

Table 6.

Accepted values of specific activity of artificial radionuclides in the zone with increased ^{241}Am and ^{137}Cs concentrations

^{137}Cs	^{241}Pu	^{238}Pu	^{241}Am	$^{239+240}$Pu
29	16.2	0.2	3.7	21.6

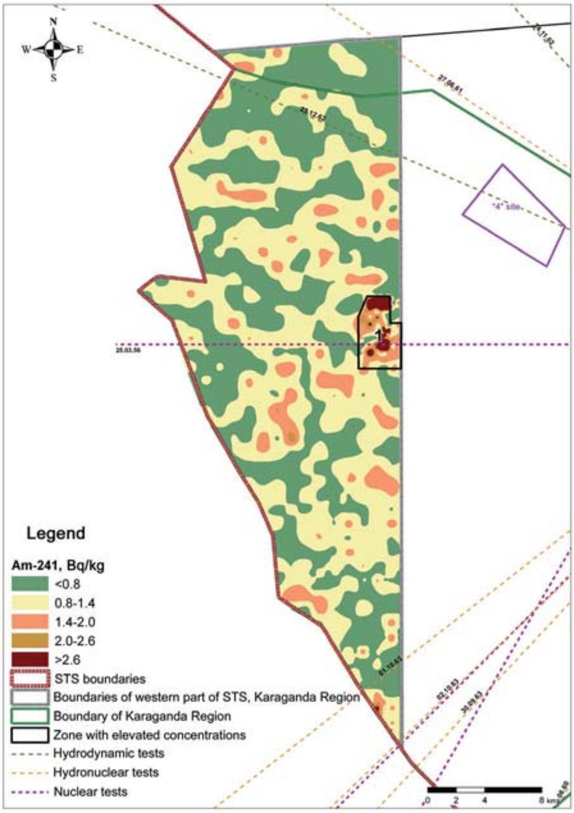


Figure 17. A zone with increased ^{241}Am concentration

2.2.4. Natural and artificial sources of radioactivity

Nowadays, in the conditions of global radioactive contamination with artificial radionuclides, the radioecological situation is an integral indicator of concentration of natural and artificial radiation sources in the environment. Radiation exposure of local people from the sources is caused both by natural and artificial radionuclides. In this context, a special attention is paid to investigations studying contribution of natural and artificial radionuclides to the radioecological situation on the studied areas.

Natural radioactivity of biosphere is formed by cosmogenic and terrestrial radionuclides. In the framework of this research we consider only terrestrial radionuclides.

Terrestrial radionuclides appeared on Earth at the moment of its formation and are mainly presented by three groups (series): radioactive families of ^{235}U, ^{238}U, ^{232}Th, and ^{40}K. Their half-life periods are long (billions of years), and therefore the radiation background formed by terrestrial radionuclides is, as a rule, constant in a certain area.

Parent elements of radioactive families of ^{235}U, ^{238}U and ^{232}Th through a chain of radioactive decays, from uranium to thallium (over 30 nuclides) turn into stable lead isotopes. Their radioactive series of decays are shown in Figure 18.

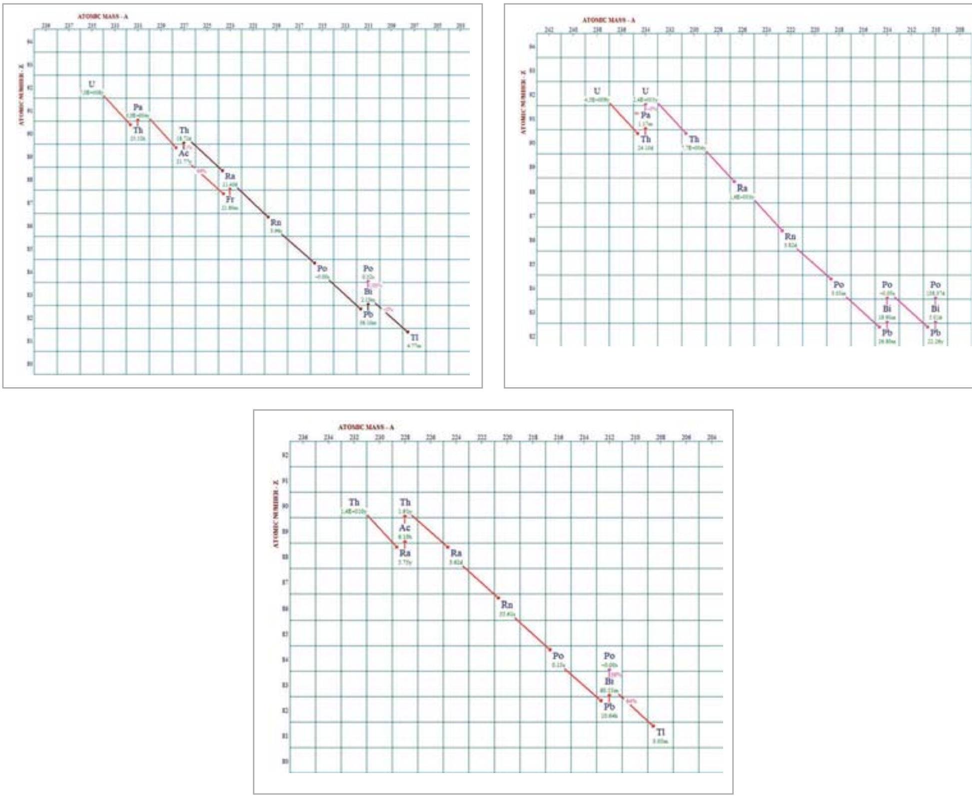


Figure 18. Series of radioactive decays of ^{235}U, ^{238}U and ^{232}Th

To obtain characteristics of radioecological situation in the studied area, a complex analysis of concentrations of natural and artificial radionuclides in soils was made. Tables 3 and 5 present average concentrations of the main dose-forming natural and artificial radionuclides in soils of the studied areas. This list of radionuclides is incomplete, because of lack of information it does not contain such radionuclides as ^{48}Ca, ^{50}Cr, ^{82}Se, ^{87}Rb, etc.

Let us calculate total α- and β-activity of natural and artificial radionuclides. It is equal to:

$$\sum E\alpha = \sum \alpha_{235_U} + \sum \alpha_{238_U} + \sum \alpha_{232_{Th}} \quad (1)$$

$$\sum E\beta = \sum \beta_{235_U} + \sum \beta_{238_U} + \sum \beta_{232_{Th}} + \beta_{40_K} \quad (2)$$

$$\sum I\alpha = {}^{238}Pu + {}^{239+240}Pu + {}^{241}Am \quad (3)$$

$$\sum I\beta = {}^{90}Sr + {}^{137}Cs \quad (4)$$

where:

$\Sigma E\alpha$ – is total α-activity of natural radionuclides

$\Sigma E\beta$ – is total β -activity of natural radionuclides

$\Sigma I\alpha$ – is total α-activity of artificial radionuclides

$\Sigma I\beta$ – is total β -activity of artificial radionuclides.

According to the chains of decays shown in Figure 18 we get:

$$\sum E\alpha = 0.9\ Bq/kg * 6 + 35\ Bq/kg * 7 + 32\ Bq/kg * 5.64 = 430{,}9\ Bq/kg$$

$$\sum E\beta = 0.9\ Bq/kg * 4 + 35\ Bq/kg * 6 + 32\ Bq/kg * 3.36 + 800\ Bq/kg = 1121\ Bq/kg$$

$$\sum I\alpha = 6.5\ \text{Bq/kg} + 1.1\ \text{Bq/kg} + 0.1\ \text{Bq/kg} = 7.7\ \text{Bq/kg}$$

$$\sum I\beta = 6.0\ Bq/kg + 18{,}0\ \text{Bq/kg} = 24\ \text{Bq/kg}$$

Thus, the contribution of artificial radionuclides into total α-activity on the studied area is equal to 1.76%, the contribution of artificial radionuclides into total β-activity is 2.1%.

To obtain a more correct estimation of contribution of artificial radionuclides and to take into account their radiation hazard we must use relative quantities, such as the ratio of radionuclide concentration to the limit of its annual intake by local people with water and food (NRB-99, Appendix 2), as it is the most probable way of radionuclide penetration into organism. Let us sum up the obtained values for natural and artificial radionuclides. The results of calculation are presented in Table 7.

Table 7.

Initial data and results of calculations

Radionuclide	Activity, Bq/kg	Max annual intake with food, Bq/year	Ratio: Activity/ Max annual intake	Sum
Artificial radionuclides ^{40}K and decay products of the series ^{232}Th, ^{235}U, ^{238}U				
^{232}Th	26 ±3	$2.2\cdot10^{3}$	$1.5\cdot10^{-2}$	$7.8\cdot10^{-1}$
^{228}Ra		$1.9\cdot10^{2}$	0.17	
^{228}Th		$2.7\cdot10^{3}$	$1.2\cdot10^{-2}$	
^{224}Ra		$1.5\cdot10^{3}$	$2.1\cdot10^{-2}$	
^{235}U	0.9 ± 0.3	$7.7\cdot10^{3}$	$1.2\cdot10^{-4}$	
^{231}Th		$4.0\cdot10^{5}$	$2.3\cdot10^{-6}$	
^{231}Pa		$7.7\cdot10^{2}$	$1.2\cdot10^{-3}$	
^{227}Ac		$3.2\cdot10^{2}$	$2.8\cdot10^{-3}$	
^{227}Th		$1.4\cdot10^{4}$	$6.4\cdot10^{-5}$	
^{223}Ra		$9.1\cdot10^{2}$	$9.9\cdot10^{-4}$	
^{238}U	23 ±2	$8.4\cdot10^{3}$	$4.2\cdot10^{-3}$	
^{234}Th		$4.0\cdot10^{4}$	$8.8\cdot10^{-4}$	
^{234}U		$7.7\cdot10^{3}$	$4.5\cdot10^{-3}$	
^{230}Th		$2.4\cdot10^{3}$	$1.5\cdot10^{-2}$	
^{226}Ra		$6.7\cdot10^{2}$	$5.2\cdot10^{-2}$	
^{210}Pb		$2.8\cdot10^{2}$	0.13	
^{210}Bi		$1.0\cdot10^{5}$	$3.5\cdot10^{-4}$	
^{210}Po		$1.1\cdot10^{2}$	0.32	
^{40}K	629 ± 40	$2.4\cdot10^{4}$	0.03	
Artificial radionuclides				
^{137}Cs	18±2	$7.7\cdot10^{4}$	$2.3\cdot10^{-4}$	$3.8\cdot10^{-3}$
^{90}Sr	6 ± 1	$1.3\cdot10^{4}$	$4.6\cdot10^{-4}$	
$^{239+240}$Pu	6.5 ± 0.8	$2.4\cdot10^{3}$	$2.7\cdot10^{-3}$	
^{238}Pu	0.10 ± 0.03	$2.5\cdot10^{3}$	$4.0\cdot10^{-5}$	
^{241}Am	1.1 ± 0.2	$2.7\cdot10^{3}$	$4.1\cdot10^{-4}$	

Thus, it is seen that cumulative radiation hazard created by artificial radionuclides at the studied area is practically 200 times lower than the radiation hazard from natural radionuclides.

2.3. Radionuclide distribution in soil

2.3.1. Radionuclide distribution along the depth of soil profile

The distribution of artificial radionuclides along the soil profile was studied in 22 short boreholes made in the most radioactively contaminated sample points (Figure 19).

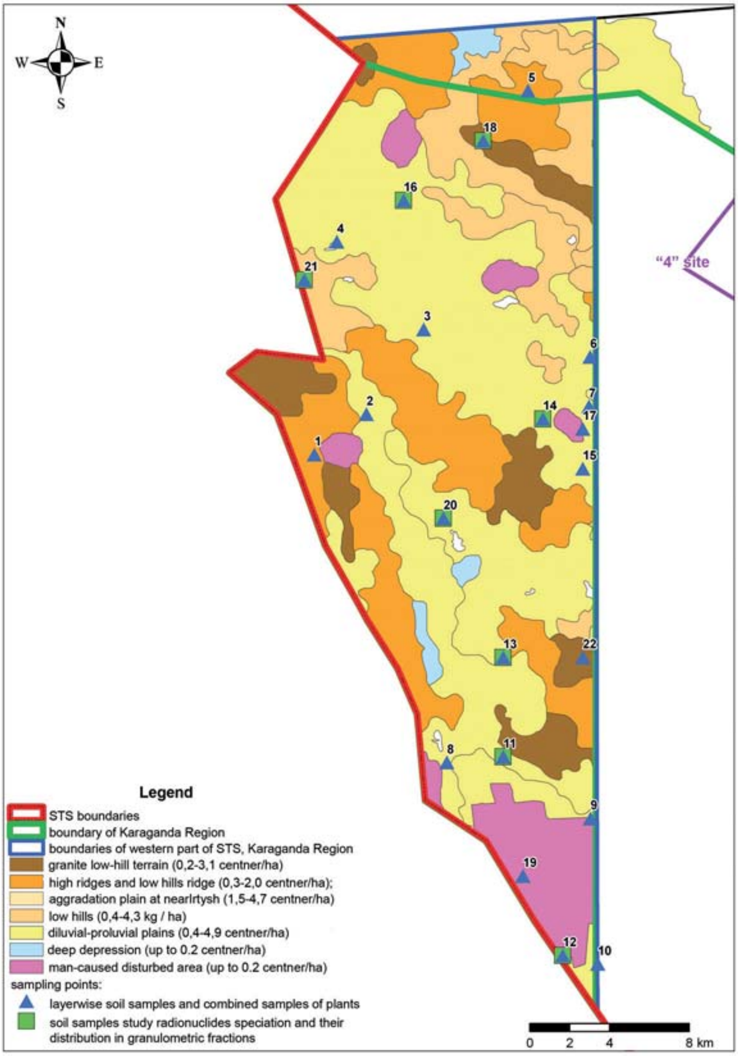


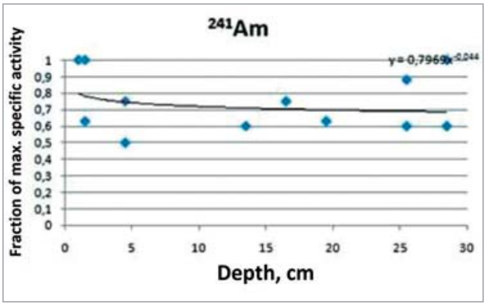
Figure 19. Location of sampling points for soil and mixed vegetation

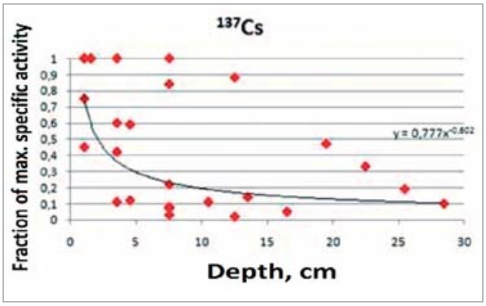
Of 22 holes, 13 are located in zonal soils developed on the hill slopes and watershed valleys. Chestnut soils, zonal soils in the area, are mainly presented by badly developed or undeveloped soils where the thickness of loose sedimentations does not exceed 40-60 cm and underlying rocks are dense rocks or residual soils. In damped conditions zonal soils are only formed by atmospheric precipitations.

On the lower hill slopes and watershed valleys were detected solonetz chestnut soils (short borehole 12) where the amount of sodium in the soil-consuming complex ranged from 5 to 15% and chestnut saline soils where concentration of freely soluble salts in the surface horizon was over 0.1% (short borehole 21). These soils have slight additional moistening due to slope runoff.

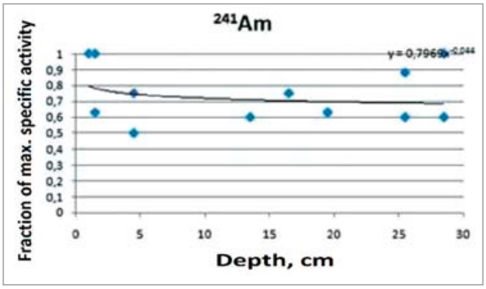
Clearly expressed azonal soils – solonetzs and highly saline soils, where the amount of absorbed sodium in the soil-absorbing complex is over 10-15%, were detected in the short boreholes 3, 4, 7, 9, 12 and 13. Saline soils with concentration of freely soluble salts in the surface horizon over 0.1% were detected in short boreholes 8, 11, 21. If saline soils have cracks, radionuclides can penetrate deeper in such soil profile than in zonal soils. In case of shallow mirror of subsoil waters freely soluble salts are accumulated in the profile, especially, in the surface horizon, which forms morphological structure of saline soils. A loose structure of saline surface horizons facilitates radionuclide penetration inside the soil. Therefore, in-depth radionuclide distributions along the soil profiles can have different structures in different soils due to their morphological differences.

The characteristics of ^{241}Am, ^{137}Cs, $^{239+240}$Pu and ^{90}Sr distributions in fractions of maximal concentration in profiles of different soil types are presented in diagrams. To draw graphs, the profiles were grouped by soil types: 13 zonal, 6 solonetz and 3 saline soils. The data below the detection level were not taken into account, therefore the number of points is much fewer than the number of measurements (Figure 20 – Figure 23).





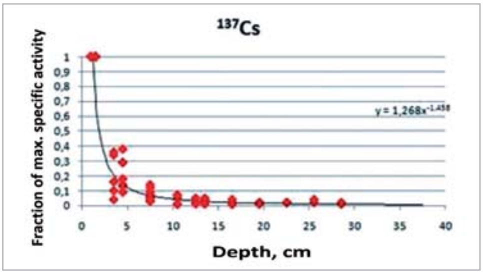
Zonal Solonetz

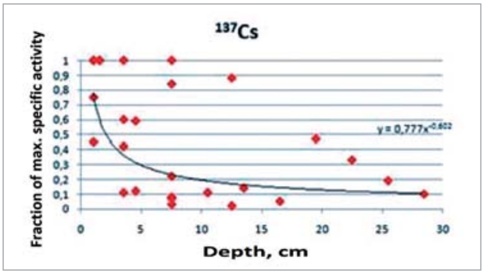


Solonchak

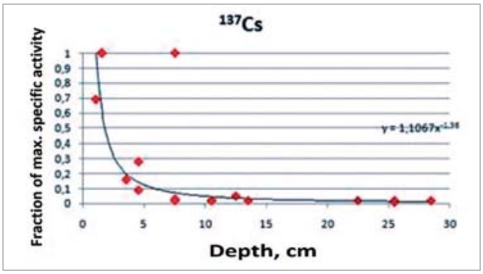
Figure 20. In-depth distribution of ^{241}Am radionuclide along soil profile

The figure shows that maximal values of ^{241}Am specific activity in zonal chestnut soils are mainly registered in upper horizons, whereas in solonchaks and, especially, in solonetz soils they can be detected in lower layers, therefore the trend of gradual decrease in concentration with depth is not clearly pronounced.





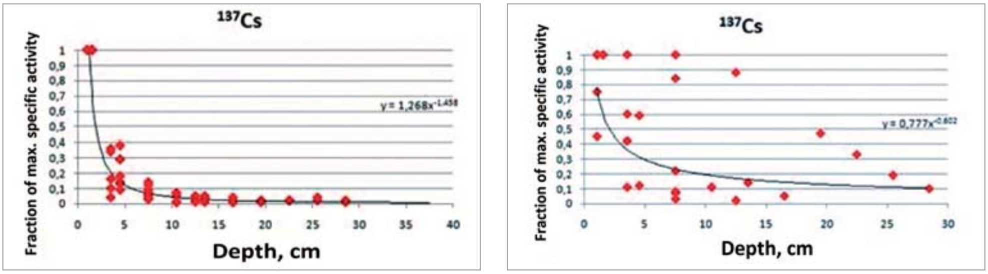
Zonal Solonetz



Solonchak

Figure 21. In-depth distribution of ^{137}Cs radionuclide along soil profile

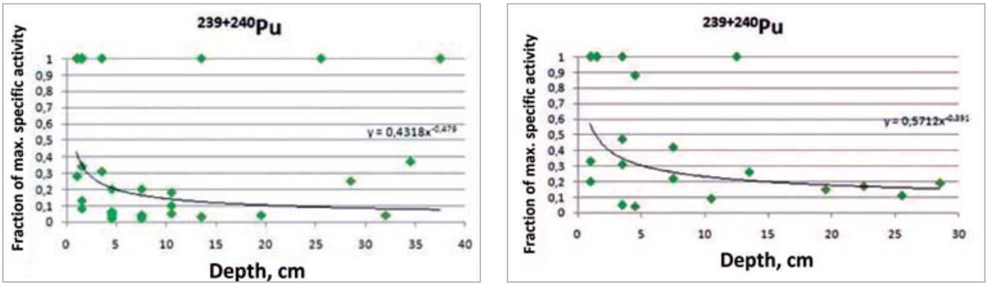
Figure 21 shows that the main amount (up to 80 %) of ^{137}Cs is contained in the upper layer 0–2, 0–3 cm, presented by the surface crust. In profile the values sharply decrease with depth. In solonetz and solonchak soils ^{137}Cs in considerable amounts penetrates to a depth of over 10-15 cm, which is especially clearly seen on the solonetz diagram.



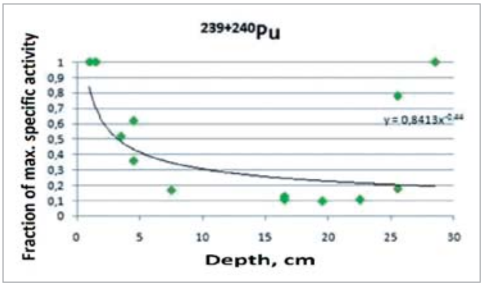
Zonal Solonetz

Figure 22. In-depth distribution of ^{90}Sr radionuclide along soil profile

Figure 22 shows distribution of ^{90}Sr radionuclide in the profile of zonal and solonetz soils. The data array is not sufficient to draw a graph of ^{90}Sr distribution in solonchak soils. Zonal soils have in-depth distribution typical of that of strontium – the specific activity smoothly decreases with depth. ^{90}Sr distribution in solonetz soils is similar to ^{137}Cs distribution - maximal concentration in the upper, fifth, layer and sharp decrease with depth. Such ^{90}Sr distribution can be explained by good absorption properties of solonetz soils.



Zonal Solonetz



Solonchak

Figure 23. In-depth distribution of $^{239+240}$Pu radionuclide along soil profile

Figure 23 shows that $^{239+240}$Pu distribution in soil profile is similar to that of ^{137}Cs. However, unlike ^{137}Cs distribution, it often shows relatively high concentrations in the middle and lower parts of the profile.

The graphs show that the distribution of ^{137}Cs and ^{241}Am specific activities mainly follows the well-known dependence, i.e. maximum is located in the upper layer 0-2, 0-3 cm with sharp decrease with depth. However, the presence of interlayers of harder mechanical composition gives increase in the radionuclide concentration at this level. Sometimes such picture is also observed at the bottom of the profile, which is caused by changes in the mechanical composition of soils. The morphological structure of azonal soils causes redistribution of radionuclides in the soil profile. For example, loose upper horizons in the solonchak or fissuring on the solonetz loamy surface can change the location of the horizon of maximal radionuclide concentration.

^{90}Sr is detected throughout the profile in all types of soils. Maximal concentrations of $^{239+240}Pu$ are mainly registered in the surface horizon, but in some cases it is detected in the second or even in the third layer. Such redistribution can be explained by dislocation of soil particles to higher depths in the conditions of extreme dryness and mobility in the upper horizons. In some boreholes a slight increase in the ^{241}Am concentration and more considerable increase in the $^{239+240}Pu$ concentrations in lower layers is observed, which can be caused by migration of mobile part of the radionuclides, probably, with slope or intersoil runoff. It should be noted that such boreholes are located at hill foots where the slope runoff increases and the ground waters outcome to the surface. The area under investigation differs from the STS northern part by terrain irregularity, numerous lakes in the inter-mountain valleys with inflow of surface and ground waters. It enables to make a conclusion that surface and ground waters may play an important role in radionuclide migration.

Therefore, ^{137}Cs, ^{241}Am and $^{239+240}Pu$ distributions in the soil profile, mainly, follow generally accepted structure, i.e. their maximal concentration is registered in the upper layer. In some cases maxima of radionuclide concentrations can slightly shift to the lower-lying horizons, which is due to morphological structure of the soil profile formed by different types of soils and specificity of natural conditions of the region. The ^{90}Sr distribution does not follow the well-known behavior, which is caused not only by the morphology of the soil profile but also by solubility and mobility of the radionuclide.

2.3.2. Speciation of artificial radionuclides in soil

Information on the ratios of radionuclide speciation in soils has an important practical application in evaluation of ecological conditions of the area. A conventional method used to determine radionuclide Speciation is stage-by-stage extraction.

Standard methods used to determine the extent and mechanisms of accessibility of radionuclides from a variety of their forms in soil detect water-soluble, exchange, mobile, non-exchange (immobile) and tightly-bound forms. Water-soluble (extracted by water) and exchange (extracted by 1M solution of ammonium acetate) forms refer to forms easily accessible for plants. Mobile radionuclide forms extracted by 1M HCl can only partially be absorbed by plants, but they form a potentially accessible reserve. Fixed radionuclide forms are released only after treatment by a 6M HCcl solution and as tightly-bound forms are inaccessible for plants.

A preliminary assessment of the ratios of radionuclide forms in soils of the studied area can be given based on the generalized data for ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am for different parts of the STS territory (areas of ground, underground and excavation explosions).

Taking into account physical chemical-properties of radionuclides, types of soils and their properties, nature and landscape of the region it was supposed that the ratios of radionuclide forms in the soils of the studied area would not consistent with the generalized results with admissible variations. The average values of concentrations of various radionuclide forms in soil and their ranges are presented in the diagrams (Figure 24).

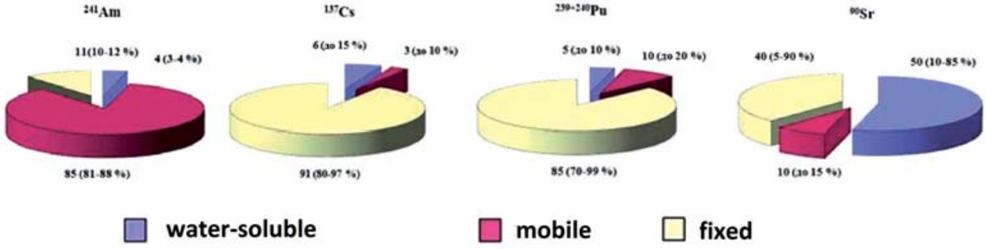


Figure 24. Ratios of concentrations of various radionuclide forms in soils in different STS areas

The generalized data for ratios of ^{137}Cs and ^{90}Sr forms in soil based on the results of studying soils in the vicinity of tunnels No. 176, 177 in the mountain range Degelen and in the STS northern part [1, 13] show that most part of ^{137}Cs is present in the fixed form, the ^{90}Sr prevailing form is an exchange form. The ratios of $^{239+240}$Pu forms were obtained in studies of soils on the "Experimental field" site, Chagan lake, gallery No. 177 and STS northern part, they show prevalence of fixed radionuclide form in soil. The results of studying of ^{241}Am forms in soil of the ecosystem in the vicinity of tunnel No. 177, "Degelen" site, and STS northern part shows that the main part of radionuclide is in mobile form.

In the framework of research studying forms of radionuclides in soils of the STS "western" territory in the areas with the highest levels of radioactive contamination and different types of soils, 8 research sites were made. The scheme of sampling points is shown in Figure 19. In the selected points samples were taken at a depth of 0-3cm on the area of 600 cm^2. Soil samples of average mass of 2500g were dried to the air-dry state, grinded in the porcelain mortar and sieved through a 1mm sieve with preliminary removal of stones, roots and other foreign bodies. Of the initial samples, the quartering batches of 100g, further used to determine radionuclide forms, were selected. Forms of radionuclides were determined by the reduced scheme with extraction of exchange, mobile and tightly-bound forms characterizing easily accessible, potentially-accessible and inaccessible forms for plants. As an extractive solvent of the exchange form we used 1M acetate-ammonium buffer, a substance widely used in stage-by-stage fractioning. The mobile form was extracted by soil treatment with 1MHCl solution. The ratio soil/leaching solution at all stages of the experiment was kept equal 1:5. The tightly-bound form was determined directly in soil remains after leaching. The amount of ^{137}Cs and ^{241}Am radionuclides in soil samples and extracts was determined by gamma-spectroscopy and the amount of $^{239+240}$Pu and ^{90}Sr was determined by radiochemical technique.

The results of determination of ^{241}Am, ^{137}Cs, $^{239+240}$Pu and ^{90}Sr forms are presented in Table 8. The data are expressed in values of specific activity of radionuclide forms recalculated per 1kg of soil and in percentage of total amount of all forms.

Table 8.

Speciation of ^{241}Am, ^{137}Cs, $^{239+240}$Pu and ^{90}Sr in soil

Sample No.	Exchange form		Mobile form		Soil-bind form	
	Bq/kg	%*	Bq/kg	%*	Bq/kg	%*
			^{241}Am			
1	1.60	-	< 2.05	-	< 0.43	-
2	0.10	1.3	6.30	83.6	1.14	15.1
3	< 1.8	-	< 1.85	-	< 0.50	-
4	< 1.95	-	< 2.05	-	1.01	-
5	2.60	-	2.0	-	< 0.47	-
6	1.10	-	6.10	-	< 0.47	-
7	1.90	-	< 2.0	-	< 0.47	-
8	< 1.6	-	< 1.80	-	0.57	-
			^{137}Cs			
1	< 6.3	-	< 5.05	-	23.7	-
2	< 5.55	-	< 6.25	-	37.2	-
3	< 5.35	-	< 5.8	-	26.2	-
4	12.0	-	< 6.05	-	37.3	-
5	10.8	20.53	9.6	18.34	32.0	61.13
6	6.6	-	< 5.7	-	35.2	-
7	< 5.6	-	5.3	-	12.4	-
8	< 6.0	-	6.0	-	44.0	-
			$^{239+240}$Pu			
1	<0.135	-	<0.137	-	1.43	-
2	0.229	-	<0.144	-	4.81	-
3	0.172	-	<0.151	-	13.96	-
4	<0.173	-	0.246	-	7.49	-
5	<0.161	-	<0.166	-	1.26	-
6	<0.138	-	<0.139	-	5.89	-
7	<0.146	-	<0.119	-	0.81	-
8	<0.147	-	<0.136	-	4.62	-
			^{90}Sr			
1	17.0	58.2	10.0	34.2	2.20	7.5
2	21.5	50.7	17.0	40.1	3.90	9.2
3	12.0	22.0	40.0	73.3	2.60	4.8
4	25.0	57.3	15.6	35.8	3.00	6.9
5	9.5	16.2	24.0	41.0	25.10	42.8
6	31.0	60.0	18.5	35.8	2.20	4.3
7	23.0	56.0	10.0	24.3	8.10	19.7
8	40.5	69.8	15.5	26.7	2.00	3.4
average	22.44	48.8	18.83	38.9	6.14	12.3
Note: * – % of total content in all forms						

Due to low level of radioactive contamination of the studied soils, in most cases in fractions, characterizing exchange and mobile forms, no quantitative data on radionuclide concentration were obtained.

The results characterizing concentration of ^{241}Am forms show that complete quantitative data were obtained only for one of eight samples. However, having analyzed all quantitative data one can deduce that mobile forms of the radionuclide have maximal values of specific activity. The ratios of ^{137}Cs forms show that in all cases a considerable amount of ^{137}Cs is in the tightly-bound form. The results obtained for radionuclide $^{239+240}$Pu show that in all 8 cases most amount of radionuclide is in the tightly-bound form. The most clearly defined picture as obtained for ^{90}Sr, the prevailing form for the radionuclide is the exchange form. Smaller amount of the radionuclide was registered in the mobile form, and the least amount was detected in the tightly-bound form.

The results of qualitative assessment of the character of contamination of the studied area by the forms of radionuclides ^{241}Am, ^{137}Cs, $^{239+240}$Pu and ^{90}Sr in soils do not contradict the generalized data for the other STS areas and can be used to forecast variations in the radioactive contamination of the studied area.

2.3.3. Radionuclide distribution in granulometric soil fractions

Studying of the distribution of artificial radionuclides in granulometric soil fractions enables to estimate contribution of soil cover into air contamination by wind dust rise and to forecast secondary local redistribution of radionuclides caused by horizontal migration due to wind erosion. In estimating radionuclide migration to the atmosphere the main role is played by tiny dust particles of a size of 100μm.

At a low wind speed of υ= 2–3 m/s, corresponding to the weather typical of middle latitudes, the tiniest radioactive dust particles rise from the ground surface by a stochastic inrush of turbulent vortices. At the above wind speed the dust does not precipitate under the action of gravity force, as the sizes of such dust particles are usually hundredths and tenths of a micron reaching 1-2 microns. At a wind speed of 10-12 m/s, occasionally observed in the region, the sizes of dust particles rising to the air may be as large as 100μm, larger particles of diameter of over 500 μm can only roll over, and fractions of a size of over 1mm do not move. Therefore, in the inflow of radionuclides to the atmosphere from the soil surface the main role is played by tiny particles less than 100μm in diameter.

To study the distribution of radionuclides, 8 point samples at a depth of 0-3 cm were taken. The scheme of location of sampling points is shown in Figure 19. The samples were taken in the points with the highest levels of radioactive contamination by the studied radionuclides and with different soil types.

The research studied the distribution of ^{137}Cs, ^{241}Am, ^{90}Sr and $^{239+241}$Pu radionuclides in soil fractions of sizes 1000–500 μm, 500–250 μm, 250–100 μm and <100 μm extracted by "wet sowing" in the water flow. The concentrations of the above radionuclides were determined in the sorted soil fractions after their drying to the air-dry state and weighing. ^{137}Cs and ^{241}Am concentrations in samples were determined by gamma-spectrometry, $^{239+241}$Pu concentration was determined by α-spectrometry with preliminary radiochemical extraction, ^{90}Sr concentration was determined using radiochemical technique.

It has been revealed that in the STS "western" areas, in the 0-3cm surface soil layer, the prevailing fraction, having a size of 1000-500 μm, makes on average 56% of the total weight. About 22% are formed by the fraction of tiny particles of a size of <100 µm. The contribution of 500–250µm and 250–100µm fractions to the total weight is, on average, 12 and 10 %, respectively. These results are in good agreement with the data obtained for the soils of the STS "northern" areas where the prevailing fraction sized from 1000 to 500µm made, on average, 50%, the next, 23%, was the fraction formed by particles less than 100 µm in diameter, followed by the fraction of 250-100µm particles, 16%, and 500-250µm particles (11%).

Therefore at the average wind speed of 4-6m/s typical of the studied "western" area a small part of the tiny-sized fraction raised from the soil surface by wind transfer will not make a considerable contribution to the radionuclide inflow to the atmosphere (Table 9).

Table 9.

Distribution of ^{241}Am, ^{137}Cs, $^{239+240}$Pu and ^{90}Sr radionuclides in granulometric fractions of the surface (0-3cm) soil layer

##	1000 - 500 µm (56 %)		500 - 250 µm (12%)		250 - 100 µm (10%)		< 100 µm (22%)	
	Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
^{241}Am								
1	<0.45	-	0.57	-	1.17	-	<0.53	-
2	0.86	-	0.75	-	<0.56	-	2.55	-
3	0.95	14.71	0.79	12.23	1.80	27.86	2.92	45.20
4	1.07	10.84	2.00	20.26	3.59	36.37	3.21	32.52
5	<0.51	-	0.56	-	7.42	-	2.41	-
6	0.92	-	<0.45	-	0.80	-	2.00	-
7	<0.55	-	<0.62	-	0.78	-	2.52	-
8	<0.48	-	2.28	-	<0.50	-	2.94	-
average		12.8		16.2		32.1		38.9
^{137}Cs								
1	13.5	13.7	18.9	19.1	19.2	19.5	47.1	47.7
2	14.1	9.9	39.5	27.8	33.7	23.7	54.9	38.6
3	21.8	21.3	22.2	21.7	30.4	29.7	27.8	27.2
4	22.7	12.8	48.9	27.7	45.7	25.9	59.4	33.6
5	24.4	12.0	33.3	16.4	41.5	20.4	104.3	51.3
6	7.9	9.5	13.4	16.2	13.9	16.8	47.6	57.5
7	27.6	13.3	50.1	24.1	44.3	21.3	86.3	41.4
8	29.8	15.5	41.4	21.5	39.9	20.8	81.1	42.2
average	20.2	13.5	33.5	21.8	33.6	22.2	63.6	42.4
$^{239+240}$Pu								
1	5.4	38.0	1.2	8.2	2.1	14.6	5.5	39.2
2	2.1	4.8	5.4	12.4	7.5	17.1	28.8	65.7
3	0.7	1.0	8.3	13.1	5.7	9.1	48.7	76.8
4	5.1	6.1	12.7	15.0	40.8	48.1	26.1	30.8
5	1.8	11.4	1.4	8.7	3.3	20.9	9.2	59.0
6	1.7	17.3	1.6	16.6	1.3	13.5	5.1	52.6
7	1.7	4.7	2.5	7.2	3.2	9.2	27.8	78.9
8	1.6	5.1	5.2	16.9	5.3	17.2	18.7	60.8
average	2.5	11.1	4.8	12.2	8.6	18.7	21.2	58.0

##	1000 - 500 µm (56 %)		500 - 250 µm (12%)		250 - 100 µm (10%)		< 100 µm (22%)	
	Bq/kg	%	Bq/kg	%	Bq/kg	%	Bq/kg	%
^{90}Sr								
1	2.6	19.5	2.6	19.5	2.2	16.5	5.9	44.4
2	7.7	27.1	6.6	23.2	7.2	25.4	6.9	24.3
3	3.9	-	5.9	-	6.6	-	< 2.1	-
4	5.9	18.1	7.7	23.6	6.5	19.9	12.5	38.3
5	4.1	16.3	2.0	7.9	13.2	52.4	5.9	23.4
6	3.8	15.0	7.3	28.7	5.0	19.7	9.3	36.6
7	7.4	20.7	5.1	14.2	6.1	17.0	17.2	48.0
8	6.8	19.7	7.6	22.0	6.8	19.7	13.3	38.6
average		23.3		21.4		20.9		34.3

The results of research show that the tiny-sized fraction (<100 µm) able to rise from the soil surface at wind speeds lower than 10-12m/s makes a considerable part of the total amount of all radionuclides in soil. Thus, the amount of ^{137}Cs radionuclide in the fraction sized less than 100 µm is on average 42%, the amount of $^{239+240}Pu$ radionuclide is 58% and the amount of ^{90}Sr radionuclide is 34% of their total amount in soil. A considerable percentage of maximal values of ^{241}Am specific activity in soil is also registered in the fraction of tiny-sized particles (<100 µm).

Lower values of ^{241}Am specific activity were registered in fractions of 100–250µm and 250–500µm. The least important in terms of ^{241}Am content is the fraction with the largest particle sizes (500–1000 µm).

Each group of particles sized 100–250 and 250–500 µm, easily involved in deflation process, contains, on average, 22 % of the total amount of ^{137}Cs radionuclide in soil. The fraction sized 500-1000 µm, not making a considerable contribution to the wind transfer, contains 13.5% of the total ^{137}Cs amount in soil.

Less important in terms of $^{239+240}Pu$ content is 500-1000µm fraction, which on average contains 31% of the total $^{239+240}Pu$ amount in soil.

The results of ^{90}Sr studying show that this radionuclide is distributed among different granulometric fractions more uniformly than other studied radionuclides.

Generalizing the results obtained in the framework of the complex ecological survey of the STS northern and western areas, it is necessary to point out a similar character of radionuclide contamination of the studied areas. The data obtained for the forms of artificial radionuclides in soils of the STS northern and western areas are in good agreement with each other and with the data for the other parts of the STS territory. The generalized data for the STS northern and western areas enable to identify forms of radionuclides in soils of the studied areas. A considerable fraction of radionuclides ^{137}Cs and $^{239+240}Pu$ is in the tightly-bound form in soil, the prevailing part of ^{241}Am is in mobile form and most part of ^{90}Sr is present in exchange form. The two studied areas also have a similar character of radionuclide distribution by granulometric fraction. The fraction with maximal concentration of studied radionuclides is the fraction with the particles whose size is <100 µm.

2.3.4. Assessment of soil quality

Natural conditions of the studied area enable to use it in national economy. The area under investigation is a cattle-breeding area. A billowy relief with thin layer of melkozem and large amounts of broken stones does not enable to use these lands as arable lands. Low hills, slopes of ridges, high and middle-height hills are lands suitable for pasturing. Vegetation complexes including fescue, feather-grass, motley grass with rare bushes of meadow-sweet, elm and other plants growing on zonal chestnut soils are the most suitable fodder for cattle in the region [14].

The most productive pastures are located in the lower parts of slopes on undeveloped chestnut or normal soils, especially of northern exposure, where moisture is better preserved and, hence, pastures have higher productivity. In the upper parts of dellivual-alluvial inter-hill valleys with rather high slopes are often located meadow-chestnut soils with higher productivity of fodder crops. In the centers of valleys such soils transform into meadow solonetzic and brackish soils, solonetzs and solonchaks covered by halophytic vegetation with spots of wormwood. Such fodder crops are of little use for animals.

Field works showed degradation of pastures in the area. Productivity of areas occupied by fodder crops on the hill and ridge slopes ranges from 0.3 centner/hectare on the tops (petrophytal-motley grass communities) to 3.1 centner/hectare the slopes (virgin wormwood-fescue-feather grass communities). In the inter-hill valleys productivity of fodder crops increases to 4.9 centner/hectare. However, in vegetation communities on solonetzic and brackish soils halophytic plants appear, which does not improve quality of fodder crops. Their productivity is about 0.4–0.7 centner/hectare. The highest productivity, up to 7.3–7.4 centner/hectare, have licorice-elymus (волоснецовые) communities widely spread on the inter-hill valleys, often growing on the shores of drying-up ponds, but the area occupied by such plants makes not more than 0.1-0.5% of the studied territory.

The main reason for pasture degradation is intensive cattle pasturing. Such type of pasturing on the background of specific natural conditions of the arid zone causes degradation of the soil-vegetation cover, which is especially clearly seen in the 2-3km zone adjacent to the winter-camps. Such a zone is sometimes trampled down to complete absence of vegetation. As a result, soils experience compaction of upper layers which worsens their water-physical parameters: volumetric weight increases, moistening decreases, soil structure is disrupted. Poor vegetation with productivity of 0.05-0.1 centner/hectare is presented by different types of wormwood, kochia and other plants badly eaten by animals. It should be noted that long-term pasturing on the areas caused not only disappearance of vegetation cover but also change in the dominants of vegetation community. Thus, different species of feather-grass, fescue, steppe motley grass were replaced by wormwoods and other weeds. Such pasturing is called "battered".

An important role in pasture degradation is played by climate of the region. In the conditions of arid climate irregular terrain and dried-up soils provide only 30-60% of vegetation cover of the soil surface, which, in its turn, makes soil very "vulnerable", subjected to wind erosion and deflation.

Soil deflation accelerates degradation of the soil-vegetable cover and makes it more destructive. The soil disperses, with loss of humus in the upper horizon the soil losses its fertility, the loose layer and the humus horizon becomes thinner, which in the conditions of poorly developed and undeveloped soils is a considerable loss [15]. Such a soil is subjected to wind erosion i.e. deflated soil cannot restore its initial vegetation cover.

However, field observations show that lands removed from agricultural use make less than 30% of the total area, and degradation causes reduction in soil density not exceeding the established limit of 1.3g/cm^3, which enables to assess the situation as rather satisfactory [16].

Therefore, the studied territory is mainly presented by not battered or slightly battered fodder areas, and soils that are classified as not deflated or slightly deflated. The only exception are pastures around camps, watering places and winter-camps where soils are highly battered and deflated, which requires soil-conservation measures and durable rehabilitation period.

2.3.5. Forecasted changes in contamination of soils with radionuclides

Radionuclide contamination of the soil surface in the western part of the Semipalatinsk Test Site within the territory of Karaganda oblast was caused by global fallouts. The concentration of radionuclides ^{137}Cs, ^{241}Am, ^{90}Sr and $^{240+241}$Pu in surface soil horizons is very low. For example, the concentration of radionuclides ^{137}Cs and ^{241}Am in soil of the farthest western part of Karaganda oblast within the STS boundaries is mainly 20-40 Bq/kg. Specific activity of ^{90}Sr seldom exceeds 8–16 Bq/kg, and specific activity of $^{240+241}$Pu in the surface horizon is mainly about 2.7 Bq/kg. The radionuclide concentration in the soil profile sharply decreases with maximum, as a rule, in the surface layer.

Thus, in spite of a long time period passed since atmospheric tests (50-60 years), maximal concentration of radionuclides fallen out on the soil surface is still registered in the surface horizon and the penetration depth does not exceed 15-20cm. Such behavior of radionuclides is explained by moisture deficiency (the amount of precipitation is 200-250mm), which does not enable them to move in the solution or under the action of water flow downwards. On the other hand, the amount of evaporating moisture is 4-5 times higher than the amount of precipitations, which explains accumulation of soluble salts, including soluble radionuclides, in the soil surface horizons. These data enable to make a conclusion that in future the picture of radionuclide distribution will not change, however, their concentration in the upper horizon will slightly decrease and the penetration depth will slightly increase as in spite of water deficiency substances and elements are redistributed in soils in the scale of geological time.

One can suppose that if artificial radionuclides over 50 years passed since nuclear tests moved to a depth of 15cm, their penetration rate will remain the same in future, i.e. about 0.3cm per year.

The role of wind as the main relief-forming factor in the conditions of continental development of the region will still be important in the spatial redistribution of radionuclides. For example, some radionuclides may remain suspended in the near-surface layer with tiny dust particles of a size less than 100µm and may be drawn by wind during storms or strong winds at a speed of over 10m/s at long distances. Dust particles of a size 100-500µm are the most active participants of dust storms, which have maximal frequency of occurrence in spring and autumn. Such particles carry about 50% of radionuclides. Hence, this amount of radionuclides can very rarely, not more often than 4-5 times a year, may travel in space. Soil particles of a size exceeding 500 µm may be dragged by vortices at a wind speed of 10-12m/s. Particles can also cover small distances by jumps at wind gusts. Thus, deflation processes may smooth over the boundaries of old traces of fallouts from radioactive clouds and dilute radionuclide concentrations in the soil cover.

2.4. State of water objects

2.4.1. Inventory of potential water use objects

Water objects in the studied "western" area are presented by both surface and subsoil waters. Surface waters are mainly presented by saline lakes, runoffs of surface waters in valleys and small streams, subsoil waters are contained in wells and boreholes. All examined objects are potential sources of drinking and household water.

As no houses, no water objects actively used by people were determined in the STS western part, one can conclude that the main type of activity of local people is cattle pasturing. In such a situation studying of surface and ground waters used to water domestic animals becomes an important problem.

As a rule, surface waters on the studied area are not used to water animals. In the places where people lived and bred cattle (abandoned summer and winter camps) water for drinking and household needs was taken from wells and boreholes, camps were equipped with drinking troughs for cattle (further – objects of water use), which does not exclude their regeneration and further usage in case of lands transfer into economic use.

To assess possibility of usage of water objects as sources of water for drinking and household needs, a detailed study including identification and registration of all potential water sources was carried out. Search for water objects was made based on archive data and available cartographic material. Most objects were detected by the available coordinates of their location, some objects were identified during visual area survey. The coordinates of identified water-use objects were registered and mapped.

All in all, 64 water objects were identified and examined in the STS western part. Of them 3 (wells with water) are located in the destroyed winter-camps, 6 are separately located wells, 17 – wells, 37 – small lakes and surface waterways formed by surface water runoff and one stream.

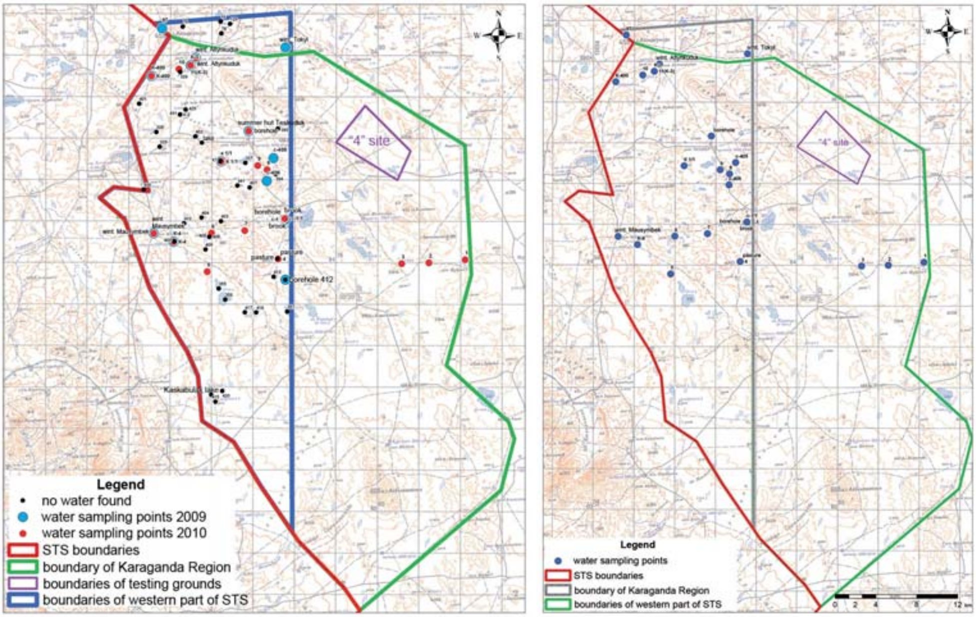
Location of all potential water-use objects identified on the territory of the STS western part is shown in figure 25.

Field works included:

- visual examination of the water objects and photographing;
- measurement of radiation parameters (EDR, density of β-particles flux);
- visual assessment of the water object state (operating/not operating, water presence/absence, close location of households, people living close to the object, cattle pasturing, etc.);
- determination of purpose and extent of object usage (if possible) and its state in terms of possibility of its further usage for drinking, agricultural and other needs;
- water sampling for analytical analyses.

Water sampling was made according to GOST 51592-2003 [17].

Samples were placed into plastic vessels of volumes ranging from 2 to 30 liters depending on the type of laboratory analyses.



a) b)

Figure 25. Water objects (a) and water sampling points (b) in the STS "western" part

Water samples were taken from 27 water objects which had water at the moment of field works. The other objects either did not have water or the water was so dirty that it was difficult to take samples. Locations of objects where water samples were taken are shown in Figure 25.

2.4.2. Assessment of quality of potential water-use objects

The water samples were subjected to the following laboratory investigations:

- measurement of concentrations of artificial radionuclides ^{90}Sr, ^{137}Cs, ^{3}H, $^{239+240}$Pu;
- determination of general chemical composition;
- determination of micro/macroelement composition.

Concentration of artificial radionuclides in surface and ground waters of the studied area

To study the levels of water contamination in the water use objects in the STS western part with artificial radionuclides, the concentration of ^{3}H, ^{137}Cs, ^{90}Sr and $^{239+240}$Pu was determined in all water samples taken from 27 water objects [18, 19].

The detection limits of used devices were about 0.01 Bq/kg for ^{90}Sr, 0.02 Bq/kg for ^{137}Cs, 15 Bq/kg for ^{3}H and 0.001 – 0.06 Bq/kg for $^{239+240}$Pu, which is 10-1000 times lower than maximal permissible concentrations for these isotopes.

The results of laboratory analyses showed that specific activities of ^{90}Sr, ^{137}Cs, ^{3}H, $^{239+240}$Pu in water samples were below the detection limits of used measurement equipment (Table 10).

Table 10.

Specific activity of artificial radionuclides in water

No	Sampling point	^{137}Cs specific activity, Bq/kg	^{90}Sr specific activity, Bq/kg	$^{239/240}Pu$ specific activity, Bq/kg	^{3}H specific activity, Bq/kg
1	97	<0.02	< 0.01	-	<13
2	Tokyl wintering	<0.02	< 0.01	-	<13
3	C-405	< 0.01	< 0.01	-	<10
4	C-406	<0.02	< 0.01	<0.002	<10
5	C-1/1	<0.03	< 0.01	<0.0006	<10
6	C-1	<0.02	< 0.01	<0.002	<10
7	Well Pasture	<0.02	< 0.01	<0.004	<10
8	2	< 0.01	< 0.01	<0.0009	<9
9	1	< 0.01	< 0.01	<0.012	<8
10	3	<0.02	<0.02	<0.004	<7
11	pasture	< 0.01	< 0.01	<0.0007	<7
12	4	< 0.01	< 0.01	<0.004	<11
13	5	< 0.01	< 0.01	<0.005	<8
14	K 4	< 0.01	< 0.01	<0.003	<8
15	Mausymbek wintering	< 0.01	< 0.01	<0.004	<7
16	6	<0.02	<0.02	<0.005	<8
17	7	< 0.01	< 0.01	<0.004	<12
18	well	< 0.01	< 0.01	<0.002	<7
19	8	<0.02	<0.02	<0.028	<13
20	9	<0.04	<0.04	<0.007	<8
21	K 1/1	<0.02	< 0.01	<0.007	<8
22	well (Teskuduk summer place)	<0.02	< 0.01	<0.02	<8
23	Altynkuduk wintering	<0.02	< 0.01	<0.0009	<8
24	K-400	<0.02	< 0.01	<0.007	<8
25	10	<0.01	<0.01	<0.005	<8
26	11 (K-3)	<0.04	<0.04	<0.003	<7
27	stream	<0.03	< 0.01	<0.0007	<9

The results of laboratory analyses did not show any presence of artificial radionuclides in water. The data obtained showed that the values of specific activities of ^{3}H, ^{137}Cs, ^{90}Sr and $^{9+240}Pu$ in water of the studied water objects according to NRB-99 were below the interference level in case of their intake with food and water.

Assessment of water objects quality in terms of general chemical indicators

In order to assess water quality by chemical indicators chemical analysis of all 20 water samples was made [20]. According to the content of the main determined components the water in all sampling points on the studied area has different composition.

According to the degree of mineralization (by V.I. Vernadsky's classification) most water samples are classified as brackish (1300–5500 mg/dm^3) and salt (20000 mg/dm^3) waters, which do not satisfy SanPiN standards for drinking water.

According to anionic composition the water is hydrocarbonate-sulphate-chloride (38%), hydrocarbonate-chloride-sulphate (11%), sulphate-hydrocarbonate-chloride (25%), sulphate-chloride- hydrocarbonate (21%) and chloride-hydrocarbonate-sulphate (5%). The average sulphate concentration is 790 mg/dm^3 (ranging from 16 to 7200 mg/dm^3). The average chloride concentration is 350 mg/dm^3 (ranging from 35.0 to 6100 mg/dm^3). The average concentration of hydrocarbonates is 510 mg/dm^3 (ranging from 61 to 1800 mg/dm^3).

According to sulphate concentration 66% of water and chloride concentration 85% of water correspond to SanPiN standards (up to 500 and 350 mg/dm^3, respectively). Measurements of water hardness show that 24% of samples have hard (8–12 mg-eqv/l) and very hard (more than 12 mg-eqv/l) water. The hydrogen indicator (pH) varies from 5 to 8.5 (average value – 6.2). Of taken samples 25% do not correspond to SanPiN standards (pH = 6–9).

Therefore, according to the results of the limited chemical analysis the water quality in only 8 objects of the total number of 20 examined objects located in the STS western part corresponds to SanPiN standards No.3.02.003.04 [21] by all studied parameters. The water in all other studied objects is undesirable to usage for drinking due to high concentrations of reference parameters, mainly, general mineralization and hardness.

Assessment of micro/macroelement composition

In the micro/macro-element analysis of water samples concentrations of the main elements such as sodium, potassium, calcium, magnesium, strontium, barium, cesium, zinc, beryllium and lead were determined. The results show that concentrations of some elements exceed MPC – maximum permissible concentrations by SanPiN standards No. 3.02.003.04.

Magnesium. The values of magnesium concentrations in the water of water objects vary from 1 to 122 mg/l, which in some cases exceeds maximum permissible concentrations for the element concentration in drinking water, which amounts to 10- 85 mg/l (SanPiN). Magnesium concentrations exceeding MPC were registered in two points – borehole K 1/1 and borehole K-4.

Potassium. The values of potassium concentrations in the studied water samples varied from 0.5 to 14 mg/l. A small rise over the standard (14 mg/l) was registered only in one surface water object – a stream located on the studied area.

Barium. The barium concentration in 5 water objects 2 and more times exceeds maximum permissible concentrations. These are water objects with numbers 1, 2, 4, 7 and 8, all they are the objects of surface water use (small lakes, runoffs of surface waters). In all other studied water samples barium concentration is much lower than the maximum permissible concentration (0.1mg/l) and varies from 0.02 to 0.09mg/l.

Beryllium. Beryllium concentrations exceeding maximum permissible concentrations were detected in 7 water objects; all they were surface water objects assigned numbers 1, 2, 3, 4, 7, 8 and 97. The values of beryllium concentration in these water objects ranged from 0.0002 to 0.003mg/l, which in some cases exceeded the established standard by an order of magnitude. In all other water objects located on the studied area the beryllium concentration in water was much lower the detection limit of used techniques and equipment. The MPC for beryllium in drinking water is 0.0002 mg/l.

Boron. The boron concentration in the studied water samples ranged from 0.12 to 1.3mg/l. The obtained values of boron concentration in water exceeded standards almost in all samples. According to SAnPiN concentration of this element in water must not exceed 0.5mg/l.

The concentrations of lead, arsenic, mercury and nickel in all samples did not exceed the maximum permissible concentrations.

Studying of water micro/macro-element composition showed that concentrations of some elements to some extent exceed maximum permissible concentrations established for drinking water. This group includes such elements as magnesium, potassium, boron and beryllium. A special attention must be paid to the beryllium concentration. In some samples its concentration is more than an order of magnitude higher than SanPiN standards for drinking water. At the same time, it should be noted that the above described parameters only provide additional information and should not be taken into account in taking decision about land transfer in economic use as they are natural properties of surface and ground waters in the studied area.

According to the concentration of micro/macro-elements the water of all other studied water objects is satisfactory and suitable for use for drinking and other purposes.

It should be noted that the water in all examined water objects is of natural origin, and most examined objects are surface water sources. In natural water the degree of toxicity of different groups of substances is defined by various factors of water environment such as mineralization, hardness, pH, ion ratio, presence of complexons, amount of oxygen, temperature, etc. All the above factors are primarily determined by climate, hydrochemical regime formed on the studied area, physical-chemical composition of soils, ability to self-purification and other factors. The concentration of microelements and general chemical composition determined in the investigations may be standard values for the studied area specified by the STS location.

As no radionuclide contamination of soils was detected during studying of soil cover of the area, taking into account physical-chemical properties of local soils one can make a conclusion that no high radionuclide concentrations in water objects are to be expected in future. This conclusion is confirmed by the fact that by its hydrogeological parameters the studied area has no inflows from conventionally "contaminated" part of the STS territory.

Taking into account the above facts one can state that in terms of radiation safety the water objects on the studied area can be classified as safe.

2.4.3. Forecasted changes in radionuclide contamination of surface and ground waters

The "western" part of the STS territory studied in this research is located on the northern slope of Balkhash-Irtysh watershed and has a slope to the northeast to the Irtysh valley.

The hydrogeological system of the area includes water-bearing horizons of porous waters and a regional complex of fracture waters. The STS "western" part is mainly presented by the following water horizons:

- recent lake sediments;
- alluvial-prolluvial sediments dated from the Middle Quaternary to recent period;
- primarily fracture waters in Paleozoic and Mesozoic strata.

Most part of the described area is occupied by ground waters of Paleozoic and Mesozoic sediments.

The data on geological structure and hydrogeological conditions as well as the mechanisms of radioactive contamination of aqueous medium in the nuclear tests zones on the STS territory were presented in detail in the materials on "western" areas [1]. In this chapter the main attention will be focused on studying of possible ways of inflow of contaminated ground waters from the sites of underground nuclear tests to ground waters of "western" areas and assessment of their migration parameters.

Atmospheric nuclear explosions

Test "Experimental field" site. The possibility of inflow of contaminated ground waters from the sites of atmospheric nuclear tests to the ground waters of "western" areas is considered in terms of possible penetration of artificial radionuclides from ground surface to ground waters. This problem was considered in detail in the materials on "western" areas where possible ways of penetration of radioactive fallouts formed during atmospheric nuclear tests to the lower-lying layers down to the level of subsoil waters were considered. The estimates have shown that the front of radionuclide contamination located at a depth of 5m on the "Experimental field" will have reached the level of subsoil waters not earlier than in $5*10^3$ years. Moreover, the absence of artificial radionuclides in ground waters spread within the test "Experimental field" site was confirmed by the results of drilling of a hydrogeological borehole. The borehole was drilled in 2009 in the northern part of "Experimental field", at the boundary of the site, the place of expected outcome of surface water runoff beyond the test site.

The possibility of inflow of contaminated ground waters from the test sites of warfare radioactive agents to the ground waters of the "western" areas is not considered as the main direction of motion of the real groundwater flow is north and northwest, whereas "western" areas are located to the southwest of the test sites. No motion of ground waters from the sites of WRA explosions in the direction of the "western" areas is expected.

Therefore the available data enable to state that no inflow of radioactive fallouts from atmospheric nuclear tests to the ground waters with their further migration to the boundaries of "western" areas is expected in the foreseeable future.

Underground nuclear explosions

The probability of inflow of ground waters contaminated with radioactive products of nuclear explosions to the ground waters of "western" areas was estimated on the base of such factors as specific features of geological structure of the STS territory and the results of testing of artificial radionuclides in hydrogeological boreholes. In the STS geological structure there are a few regional fractures spreading north-west and large fractures of meridian and northwest stretching. A complex of factors including specific features of geological structure and the impact of underground nuclear explosions on the geological strata caused formation of complicated geological-physical structures in the rock strata where radionuclides can migrate with ground waters. It was established that the most important role in the distribution of water resources is played by the zones of tectonic fractures (Figure 26), where the speed of groundwater motion is higher than that in the surrounding structures.

"Degelen" site

Among the main possible ways of inflow of contaminated ground waters from the places of underground nuclear explosions on the "Degelen" site to the waters of "western" areas the most important are the following directions.

As the main direction of movement of contaminated ground waters one can consider the direction to the basin of the Karabulak stream with further water inflow to the zones

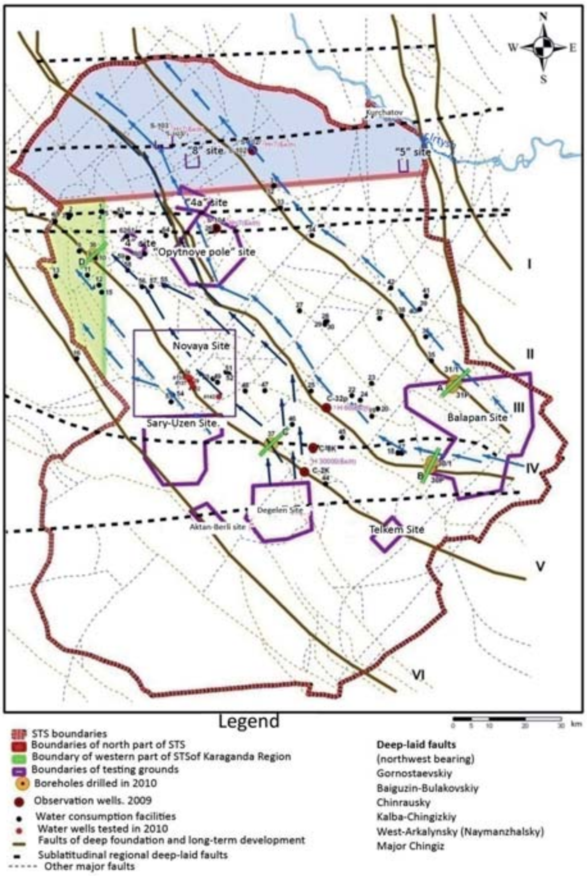


Figure 26. STS territory. Main directions of possible motion of contaminated ground waters

of influence of Western-Arkalyk and Kalba-Chingiz regional fractures. This version is confirmed by the data of the 2009 field works. In some boreholes drilled in the zone of influence of Western-Arkalyk regional fracture, ^{3}H concentration in subsoil waters was as high as 30 kBq/l. In the borehole S-32r located at a distance of 40km from the Degelen mountains and in the borehole drilled in the zone of Kalba-Chingiz fracture ^{3}H concentration was 0.06 kBq/l [22].

Results of the 2010 investigations. To study possible movement of contaminated ground waters in the zone of influence of Western-Arkalyk fracture in the direction of western areas, in 2010 investigations were carried out in two sectors along the fracture trace. The first sector (sector C) was made at a distance of 12km from the place of intersection of the fracture trace with the valley of the Karabulak stream (Figure 26). The purpose of investigations in this sector was to determine possible radionuclide contamination of ground waters spread in the zone of the fracture influence, in the water flow beyond the microbasin of the Karabulak stream. It was important to determine radionuclide migration along the facture zone in the direction of "western" areas. The second sector (sector D) was also located in the zone of fracture influence, but directly in the "western" area. It was necessary to carry out works in the sector to determine possible inflow of contaminated ground waters not only from the "Degelen" site but also from sites "Sary-Uzen" and "Balapan".

By the results of geophysical investigations, in the studied sectors the zones with maximal water-flooding were determined and hydrogeological boreholes 36p and 37p were drilled. The boreholes pierced the regional water flows in the exogenous fissuring zone. The laboratory analyses showed that concentrations of artificial radionuclides in ground waters in the studied areas were below minimal permissible activity of used equipment (Table 11).

Table 11.

Results of analysis of samples from drilled boreholes

Borehole number	Fracture trace	^{137}Cs, Bq/l	^{90}Sr, Bq/l	^{3}H, kBq/l
36P	Western-Arkalyk	<0.01	*	<0.018
37P	Western-Arkalyk	<0.01	<0.01	<0.019
Note: * no data				

The above values are not hazardous and are far below the interference levels for people for water intake with water and food established by NRB-99 (Appendix p-2).

Thus, the results of investigations enable to make a conclusion that there is no inflow of contaminated ground waters through the zone of regional Western-Arkalyk fracture to the ground waters of western territories.

To estimate the time of possible inflow of ground waters contaminated by artificial radionuclides to the boundaries of "western" territories we will use the data on hydrogeological conditions obtained in detailed survey of "Karadzhal" deposit located in the northern part of "Degelen" site. The calculation is made for radionuclide tritium. It is known that ^{3}H moves with ground waters as tritium water and is not absorbed by mountain rocks. Therefore the time of ^{3}H arrival at the boundaries of "western" territories can be determined taking into account the distance from the crossing of the Karabulak stream with the trace of Arkalyk fracture to the eastern boundary of "western" areas. The results of hydrogeological investigations show that maximal speed of groundwater movement in the vicinity of the deposit is 2.5m/day. Thus, taking the speed of groundwater movement and the distance from the "Degelen" site to "western" areas we can calculate the time during which the groundwater will cover the distance – about 70 years. Taking into account that over 40 years have passed since the first nuclear explosion, tritium contaminated ground waters from the "Degelen" site may appear at southern boundary of "western" territories in about 35 years.

"Sary-Uzen" site

From the "Sary-Uzen" site the contaminated ground waters can get into ground waters of "western" territories along feathered tectonic structures of Western-Arkalyk regional fracture. To get general information on the levels of radioactive contamination of ground waters we present the new data and the 2010 data. In 2005, 20 hydrogeological boreholes were tested on the "Sary-Uzen" site (Figure 27).

The results of laboratory analyses showed that concentrations of radionuclides in ground waters on the territory of the test site were: up to 3 mBq/l for ^{137}Cs, up to

10 mBq/l for ^{90}Sr, over 500 kBq/l for ^{3}H. These data show that the main radioactive pollutant on the test site is ^{3}H. ^{137}Cs and ^{90}Sr concentrations are not hazardous and do not exceed permissible values for drinking water.

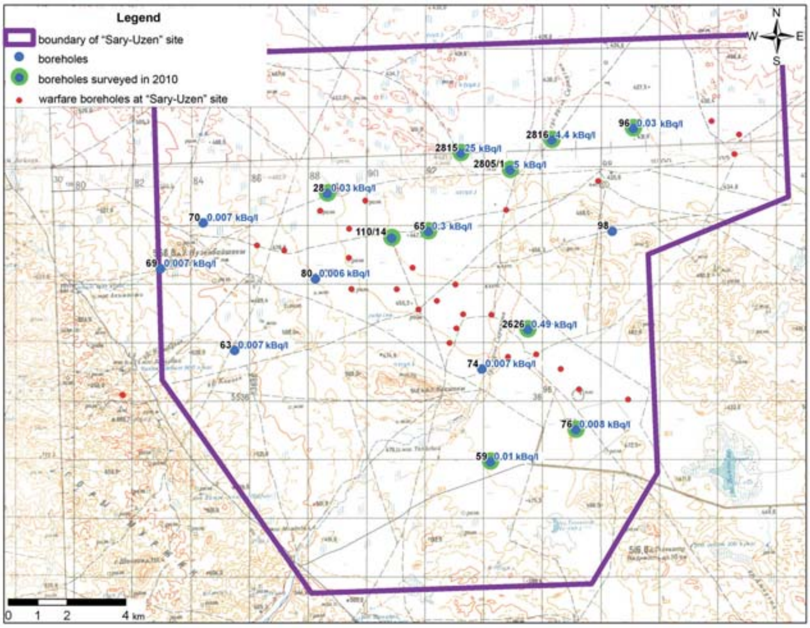


Figure 27. Scheme of location of boreholes on the "Sary-Uzen" site

Results of the 2010 investigations. To verify the available data, 10 hydrogeological boreholes were tested on the "Sary-Uzen" site in 2010 (Table 12).

Table 12.

Comparative values of tritium specific activity in water samples taken in hydrogeological boreholes on the "Sary-Uzen" site

Borehole number	Specific activity ^{3}H, kBq/l		Borehole number	Specific activity ^{3}H, kBq/l	
	prior 2010	2010		prior 2010	2010
59	0.01	<0.008	2818	0.01	-
76	<0.007	<0.008	C-28	0.06	-
2626	0.49	0.2	C-98	0.009	-
28	<0.21	0.03	C-2627	0.012	-
2815	-	25	C-2692	0.012	-
2816	4.4	4	C-2815	0.8	25
2805/1	-	5	80	<0.006	-
63	<0.007	-	104/1	46.8	-
69	<0.007	-	116	<0.007	-
70	<0.007	-	125	482	-
74	<0.007	-	110/14	65.8	30

Borehole number	Specific activity ^{3}H, kBq/l		Borehole number	Specific activity ^{3}H, kBq/l	
	prior 2010	2010		prior 2010	2010
189B	0.017	-	96	0.031	0.03
2805	0.018	-	65	0.045	0.3
2811	3.2	-			

An analysis of obtained results shows that though dynamics of ^{3}H concentration on the test site cannot be estimated as unambiguous, in general, there exists a tendency to gradual decrease in its concentration in ground waters.

It should be kept in mind that the "Sary-Uzen" site is located very close to the boundaries of "western" territories. What is more, this area is less studied that other STS areas. There is still no geological map of the area, and ground waters are not well studied. In this case in order to forecast possible development of radioecological situation it is necessary to have monitoring points not only in the studied area but also near the sources of contamination.

"Novaya" site

To study possibility of outflow of contaminated ground waters beyond the boundaries of the "Sary-Uzen" site in the direction of "western" territories we used testing data for of hydrogeological boreholes located on the "Novaya" site (Figure 28).

This test site is located on the northern boundary of the "Sary-Uzen" site i.e. on the possible route of groundwater motion in the direction of "western" territories. During nuclear tests the "Novaya" site was used for preparatory works for UNE in boreholes. For this purpose 19 hydrogeological boreholes were drilled on the "Novaya" site. In 2007, to study the character of migration of artificial radionuclides 7 boreholes on the "Novaya" site were tested. The results of analyses are presented in table 13.

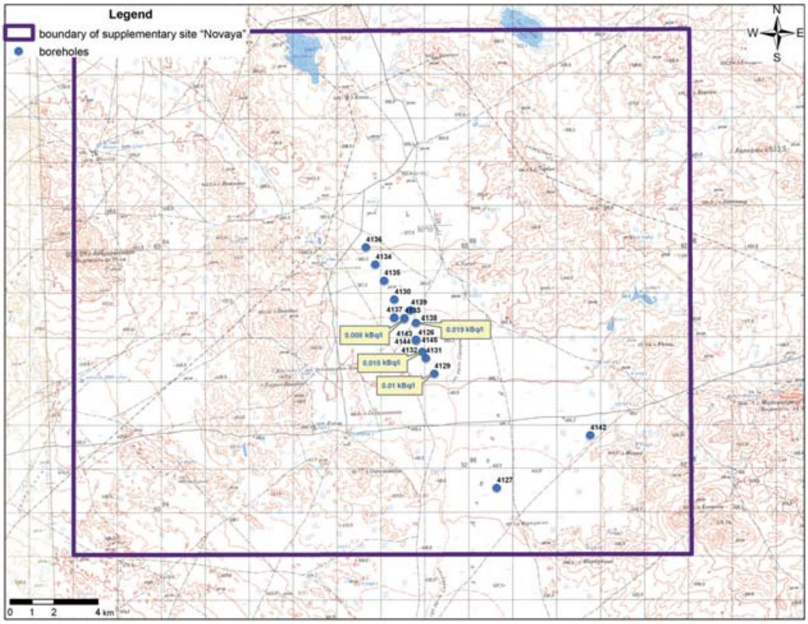


Figure 28. A scheme of location of observational boreholes on the "Novaya" site

Table 13.

Analyses of water samples from the boreholes

Borehole No.	^{3}H, kBq/kg, kBq/l	Error
4133	<0.007	-
4129	0.021	0.005
4132	0.010	0.004
4138	0.012	0.005
4133	0.008	0.004
4137	0.010	0.005
4142	<0.006	-

The results of analyses showed that ^{3}H concentration in ground waters varied from 7 to 20 Bq/l, which is much lower than the interference level for intake of some radionuclides with water (NRB-99, Appendix P-2).

Results of the 2010 investigations. To estimate possible transfer of contaminated ground waters from the "Sary-Uzen" site towards "western" territories 3 earlier drilled boreholes were tested on the "Novaya" site (Figure 26). According to the results of laboratory analyses no artificial radionuclides were detected on the studied areas. Therefore, the results of testing of hydrogeological boreholes show that no motion of ground water flows contaminated with artificial radionuclides towards "western" territories is now observed.

"Balapan" site

To study the character of radioactive contamination of ground waters on the "Balapan" site we used hydrogeological boreholes equipped for routine observations of ground waters during underground nuclear tests. The boreholes were drilled at different distances from "combat" boreholes, and their main purpose was to study the UNE influence on the dynamics of ground waters. According to the available data, there are over 100 of such boreholes on the "Balapan" site. The scheme of location of found and tested boreholes on the "Balapan" site is shown in Figure 29.

The results of investigations carried out in different years show that high values of specific activity of ^{90}Sr and ^{137}Cs in ground waters within the boundaries can be observed only in the vicinity of epicenters of nuclear explosions. At a distance of 300m from the heads of boreholes the values of specific activities of radionuclides go down to mBq/l. Therefore, due to low concentration the available data do not show any peculiarities in the ^{137}Cs and ^{90}Sr distribution in ground waters. At the same time ^{3}H concentration in ground waters varies widely from the minimal detected activity (7Bq/l) to maximal values reaching $5*10^{6}$ Bq/l.

Results of the 2010 investigations.

Testing of available hydrogeological boreholes. In 2010 to verify the available data we tested 8 hydrogeological boreholes located within the boundaries of the "Balapan" site (Figure 29). Table 14 presents the results of laboratory analyses on determining ^{3}H concentrations and maximal values of ^{3}H concentrations obtained by the results of previous works.

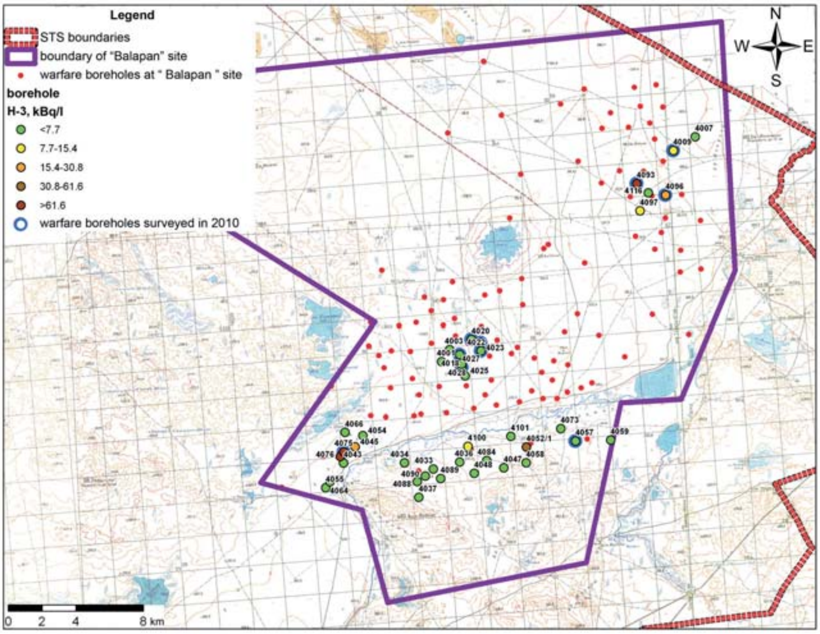


Figure 29. A scheme of location of boreholes on the test site "Balapan

Table 14.

Comparative results of tritium specific activity in water samples taken from hydrogeological boreholes of the "Balapan" site

Borehole number	^{3}H specific activity, kBq/l	
	before 2010	in 2010
4009	10.5	5
4018	5.4	0.05
4020	1.24	0.24
4027	1.2	1.8
4057	0.03	<0.013
4075	394	22
4093	400	300
4096	15	5

The results of laboratory analyses on determining ^{3}H concentrations and maximal values of ^{3}H concentrations obtained by the results of previous works showed a tendency of gradual decrease in ^{3}H concentration in ground waters on the "Balapan" site.

Investigations of Kalba-Chingizsky and Chinrausky regional fractures. The most probable direction of the motion of contaminated ground waters from the "Balapan" site is northwestern direction along the zone of influence of Kalba-Chingizsky fracture (Figure 26). The less probable is the route of the initial water motion along the zone of Chinrausky fracture with further flows displacement towards "western" territories along sub-latitudinal fractures.

In 2010, in order to study possible migration of artificial radionuclides in the above directions we carried out radioecological investigations of ground waters including geophysical investigations, drilling, experimental-filtering observations in drilled hydrogeological boreholes and laboratory analyses of radionuclide and chemical composition of ground waters. All works were done in the zones of regional fractures in two sectors A and B (Figure 26). In order to detect water-conducting zones, prior to these investigations, we carried out geophysical investigations in the studied zones. Taking into account geophysical data in each sector we drilled one borehole to a depth of 15m to study porous waters and one borehole to a depth of 60m to study ground waters in the zone of exogenous fissuring. In the zone of influence of Chinrausky fracture no porous waters were detected. In the other three boreholes experimental-filtering works were carried out, after which groundwater samples for chemical and radionuclide analyses were taken.

The results of laboratory analyses showed that ground waters in the zone of Kalba-Chingizsky fracture Sector B) the concentrations of artificial radionuclides ^{137}Cs and $^{239+240}Pu$ was below MPA and ^{3}H concentration was 0.05 kBq/l. In ground waters spread in the zone of Chinrausky fracture $^{239+240}Pu$ concentration was 0.0024 Bq/l and ^{3}H concentration was 0.75 kBq/l.

The obtained values of radionuclide concentration are not radioactively hazardous and are much lower than the interference level for radionuclide intake with water and food established by NRB-99. Therefore, the obtained data enable to conclude that no unfavorable tendencies in the development of radioecological situation related to possible inflow of contaminated ground waters along the regional fractures from the "Balapan" site to the boundaries of "western" territories are observed.

To estimate time of possible inflow of ground waters contaminated with artificial radionuclides to the boundaries of "western" territories we used hydrogeological parameters obtained in detailed exploration of deposit "Karazhyra". According to the results of hydrogeological investigations the average speed of ground waters on the territory of the deposit is 170m/year. If we take this speed of groundwater motion and distance from the "Balapan" site to the boundaries of "western" territories, we can conclude that ^{3}H contaminated ground waters from the test site "Balapan" can have appeared at the southern boundary of "western" territories not earlier than in 480 years.

Water-use objects. As additional information we analyzed the data for water use objects located directly in the STS western part and in the adjacent areas.

An analysis of the data for water objects located on the way of possible movement of contaminated water flows from the UNE test sites to "western" territories showed that contamination of artificial radionuclides in the water of the water-use objects was much lower than the interference levels for people for their intake with water and food established by NRB-99.

Therefore, the results of the above investigations enable to conclude that according to the level of contamination of surface and ground waters the STS "western" territories can be used for any agricultural works without any limitations.

It should be noted that planning works on mining of mineral resources in the area it is necessary to carry out additional investigations. The actuality of the problem is caused by the location of the "Sary-Uzen" site at a distance of 16 km from eastern boundaries of "western" territories. It should be taken into account under the action of water pumping during mining a depression hole will be formed (drying hole). The area of influence of the hole may include the areas of formed UNE tests and, hence, areas with ground waters contaminated with UNE radioactive products. Formation of such a drying hole is usually accompanied by increase in the slopes of piezometric surfaces of ground waters, which enhances migration processes and groundwater motion in the direction of excavations. Such processes may provoke inflow of contaminated ground waters to the boundaries of the deposit and cause radiation hazard for workers and radioactive contamination of mining products.

Here we present recommendations on organization of the system of observations of the ground waters in the area of "western" territories with their inclusion into the state monitoring system.

To control possible inflow of contaminated water flows from the nuclear test sites to the ground waters of "western" territories and to determine at the initial stage any unfavorable tendencies in the development of radioecological situation it is necessary to organize additional observation hydrogeological points, which will be included in the unified state monitoring system, on the STS territories. For this purpose it is necessary:

To carry out revision of all boreholes on the "Sary-Uzen" site. To use the results of testing to choose 3 boreholes for long-term monitoring of ground waters. To carry out inspection once a year. The main controlled radionuclide is ^{3}H. The main purpose of the observation point is to control movement of radionuclides with the ground water flow leaving the "Sary-Uzen" territory.

To carry out revision of all boreholes on the "Novaya" site. To use the results of testing to choose 3 boreholes for long-term monitoring of ground waters. To carry out inspection once a year. The main controlled radionuclide is ^{3}H. The main purpose of the observation point is to control movement of radionuclides with the ground water flow leaving the "Sary-Uzen" territory.

To drill and equip for observations 3 boreholes along eastern boundary of "western" territories. To carry out inspection once a year. The main controlled radionuclide is ^{3}H. The main purpose of the observation point is to control movement of radionuclides with the ground water flow leaving the "Sary-Uzen" territory and moving in the direction of "western" territories.

2.5. State of the air basin

To study air quality on the STS and adjacent areas different targeted investigations were carried out. The information on the air on the territory of Kurchatov-city and "northern" part of the STS territory was presented in [1]. It was established that volumetric activity of radionuclides in air of the studied areas was several orders of magnitude lower than the standards established by the NRB-99.

Studies of volumetric activity of artificial radionuclides in the vicinity of the test site "Opytnoye pole" showed values considerably exceeding maximum permissible values. It means that it is hazardous to stay for a long time and, what is more, to do agricultural works (causing dust rise) near such objects. However, the transboundary transfer of radioactivity beyond the boundaries of such test areas and, especially, beyond the boundaries of the test site is insignificant, and is not harmful now and will not be harmful in future [23].

In studying the air basin of the STS western part we made theoretical assessment of possible radioactive contamination of the atmosphere. During field experimental works the samples of air aerosols were taken, equivalent equilibrium volumetric radon and thoron activities and surface radon escalation were determined. As there are no villages on the territory, the observation points were located in abandoned winter-camps and summer-camps.

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

The results of investigations showed that specific activities of artificial radionuclides in the surface soil layer in the western part of the STS territory were: 6Bq/kg for ^{90}Sr, 18 Bq/kg for ^{137}Cs, 6.5 Bq/kg for $^{238+239+240}$Pu and 1.1 Bq/kg for ^{241}Am. The values of specific activities of artificial radionuclides were also determined in the zone with increased concentration of artificial radionuclides in the surface (5cm) soil layer, they were: ^{137}Cs – 29 Bq/kg, $^{238+239+240}$Pu – 8.6 Bq/kg, ^{241}Am – 3.7 Bq/kg. As the values of ^{90}Sr specific activity we took the average activity of the radionuclide on the studied territory.

Light soils widely spread on the studied area are most subjected to dust formation, which causes rise of artificial radionuclides from soil surface to air. Climatic conditions of the studied area (dust storms, strong winds) can also cause secondary rise of artificial radionuclides contained in soil. Therefore, in theoretical estimations it is necessary to take into account radionuclide concentration in the small-sized fraction (<100 μm), which will take part in the wind rise and transfer at a wind speed less than 6m/s.

As a result of studying of granulometric composition of soils it was determined that 22% of the total soil weight belongs to the small-sized fraction (<100 μm). Table 15 presents concentrations of radonuclides ^{137}Cs, ^{90}Sr, $^{238+239+240}$Pu and ^{241}Am in the surface (5cm) soil layer in the granulometric fraction.

Table 15.

Percentage concentration of radionuclides in the granulometric fraction (<100 μm) from the soil of studied area

Average concentration of radionuclides in the granulometric soil fraction (<100 μm), %			
^{137}Cs	^{90}Sr	$^{238+239+240}$Pu	^{241}Am
42.4	34.3	58.0	38.9

Taking into account average concentration of the small-sized fraction, average values of specific activities of artificial radionuclides in soil and average percentage concentration of radionuclide in the fraction, one can calculate specific activity of radionuclides in the granulometric soil fraction (<100 μm). The results of calculation are presented in Table 16.

Table 16.

Specific activity of radionuclides in the small-sized soil fraction (<100 μm)

^{137}Cs	^{90}Sr	$^{238+239+240}Pu$	^{241}Am
Average values of radionuclide concentrations, Bq/kg			
35	9.4	17	1.9
Average values of specific activity of radionuclides in zones with increased concentration of artificial radionuclides, Bq/kg			
56	9.4*	23	6.5
Note: * - average values of specific activity of radionuclides for all territory are used			

In estimations of concentrations of artificial radionuclides in air the values of radionuclide specific activity in granulometric soil fraction (<100 μm) were used.

The volumetric activity of radionuclides in air of the STS western part was expressed as:

$$C_{airi} = C_i \cdot \rho_{sus},$$

where C_{airi} is a volumetric activity of the *i*-th radionuclide in air (Bq/m^3);
C_i is a specific activity of the *i*-th radionuclide in the small-sized soil fraction, Bq/kg;
ρ_{sus} is the average annual air dustiness, kg/m^3.

According to [24], the average annual air dustiness in the open air and in premises is $1 \cdot 10^{-7}$ kg/m^3. From the report published by the European Commission [25] it follows that natural dusting or human activities may cause a 10-fold increase in the air dustiness, i.e. to $1 \cdot 10^{-6}$ kg/m^3. Therefore, in estimating radionuclide concentration in air we will consider both values.

The concentration of artificial radionuclides in the air of western part of the STS territory was estimated by the average values of specific activity and increased concentrations of artificial radionuclides in the surface soil layer. The initial data are presented in table 16.

Calculated values of the volumetric activity of artificial radionuclides in the air of the studied area with account for the average annual air dustiness are presented in the table below (Table 17).

Table 17.

Expected volumetric activity of artificial radionuclides in the air of western territory and areas with increased concentrations of artificial radionuclides

Average annual air dustiness (ρ_{sus}), kg/m^3	Volumetric activity of radionuclides in air at average values of specific activity in soil, Bq/m^3			
	^{137}Cs	^{90}Sr	$^{238+239+240}Pu$	^{241}Am
10^{-6}	$3.5 \cdot 10^{-5}$	$9.4 \cdot 10^{-6}$	$1.7 \cdot 10^{-5}$	$1.9 \cdot 10^{-6}$
10^{-7}	$3.5 \cdot 10^{-6}$	$9.4 \cdot 10^{-7}$	$1.7 \cdot 10^{-6}$	$1.9 \cdot 10^{-7}$
	Volumetric activity of radionuclides in air in the zone with increased concentration of artificial radionuclides, Bq/kg			
10^{-6}	$5.6 \cdot 10^{-5}$	$9.4 \cdot 10^{-6}$	$2.3 \cdot 10^{-5}$	$6.5 \cdot 10^{-6}$
10^{-7}	$5.6 \cdot 10^{-6}$	$9.4 \cdot 10^{-7}$	$2.3 \cdot 10^{-6}$	$6.5 \cdot 10^{-7}$
AVA_{pop}, Bq/m^3	$2.7 \cdot 10^{1}$	2.7	$2.5 \cdot 10^{-3}$*	$2.9 \cdot 10^{-3}$
Note: * as admissible volumetric activity of $^{238+239+240}Pu$ the value of $2.5 \cdot 10^{-3}$ for one ^{239}Pu radionuclide is taken				

The volumetric activity of artificial radionuclides in the air of western part of the STS territory at the average values of specific activity and in the zones with increased concentrations of artificial radionuclides in the surface soil layer is much lower (2-6 orders of magnitude) than the values admissible according to NRB-99.

The 2009 theoretical estimations of artificial radionuclides concentration in the air of northern part of the STS territory made for the case of their wind transfer from the contaminated zone (test site "4a") to the near-surface atmosphere showed that at a distance of 500m the contribution of artificial radionuclides to the air of "northern" territory is insignificant. Therefore we did not make estimations of possible changes in activity concentrations of artificial radionuclides in the air of "western" part of the STS territory with account for wind transfer of radionuclides from the most contaminated areas of the STS territory.

Thus, the above theoretical estimations of artificial radionuclides concentration in the air of western part of the STS territory showed that volumetric activity of artificial radionuclides at the average values of specific activity and in the zones with increased concentrations of artificial radionuclides in the surface soil layer do not exceed admissible values for population.

2.5.2. Experimental data on concentrations of natural and artificial radioniclides in the air of the studied area

To obtain the data most fully characterizing the air basin, the samples were taken in the uninhabited villages in summer, in the period of the highest air dustiness. Figure 30 shows location of populated areas on the studied territories.

Samples were taken in the center of the populated area with a mobile sampler JAP-50 equipped with a mechanical counter of the volume of pumped air (in m^3). The sampler capacity is 50–60 m^3/h. As a filtering material the cloth "Petryanova" was used. The area of the filter working surface is 250 cm^2.

The aspiration time for one sample as calculated based on technical characteristics of spectrometric devices used in laboratory measurements, with the sampling time for one sample equal to 8 hours and volume of pumped air – of about 400 m^3.

Samples taken in field works were delivered to the laboratories of the Institute for laboratory analyses on concentration of natural and artificial radionuclides. The results of gamma-spectrometric and radiochemical measurements are presented in table 18.

Table 18.

Results of gamma-spectrometric and radiochemical measurements of samples of air aerosols

No	Sampling point	Radionuclide volumetric activity in air, Bq/m^3									
		^{7}Be	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu	^{90}Sr	$^{239+240}$Pu
1	Teskuduk	$<9*10^{-4}$	$< 7*10^{-3}$	$< 7*10^{-4}$	$< 9*10^{-4}$	$< 9*10^{-5}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$	<0,03	$< 9*10^{-5}$
2	Mausymbek	$<9*10^{-4}$	$< 7*10^{-3}$	$< 1*10^{-3}$	$< 1*10^{-3}$	$< 1*10^{-5}$	$< 1*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$	<0,04	$< 5*10^{-5}$
3	Tokyl	$<8*10^{-4}$	$< 7*10^{-3}$	$< 7*10^{-4}$	$< 9*10^{-4}$	$< 8*10^{-5}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$	<0,04	$<4*10^{-4}$
4	Altynkuduk	$<9*10^{-4}$	$< 8*10^{-3}$	$< 8*10^{-4}$	$< 5*10^{-4}$	$< 1*10^{-5}$	$< 2*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$	<0,02	$< 9*10^{-5}$
5	Nadirkura	$<9*10^{-4}$	$< 6*10^{-3}$	$< 6*10^{-4}$	$< 6*10^{-4}$	$< 6*10^{-5}$	$< 1*10^{-4}$	$< 4*10^{-4}$	$< 3*10^{-4}$	<0,03	$< 6*10^{-5}$
AVA_{pop}, Bq/m^3		$5.0*10^{3}$	$3.1*10^{1}$	$4.9*10^{-3}$	$3.0*10^{-2}$	$2.9*10^{-3}$	$2.7*10^{1}$	$1.1*10^{1}$	$0.29*10^{1}$	2.7	$2.5*10^{-3}$

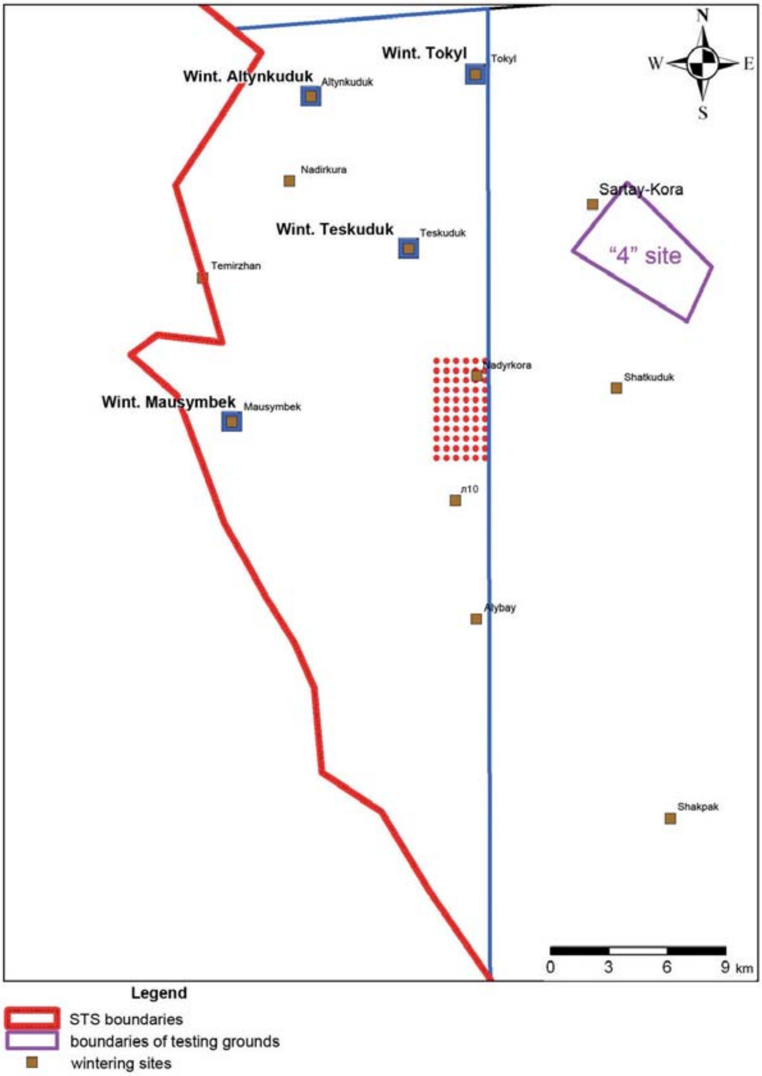


Figure 30. A scheme of location of populated areas on "western" territory

The results of laboratory tests showed that concentrations of artificial radionuclides in the air of the studied area did not exceed the values established by NRB-99.

2.5.3. Radon concentration in the air of the studied area

To estimate radon hazard on the territory, the radon exhalation and equivalent equilibrium volumetric activity (EEVA) of ^{222}Rn and ^{220}Rn were measured. The radon exhalation was measured with Ramon-Radon-01 and alpha-radiometer RZA-01-SOLO in the household structures in populated areas according to [26]. The results of measurements are given in table 19.

Table 19.

Results of field measurements

No.	Measurement points	EEVA ^{222}Rn, Bq/m^3	EEVA ^{220}Rn, Bq/m^3	Radon exhalation mBq/(m^2*s)
1	Teskuduk	13	<8	57
2	Mausymbek	11	<8	67
3	Tokyl	10	<8	65
4	Altynkuduk	15	<8	53
5	Nadirkura	12	<8	60

As a result of investigations it was established that this area does not refer to radon-hazardous areas as the value of radon exhalation is less than 80 mBq/(m^2*s).

The volumetric activity of radon and thoron in the atmospheric air in the period of observations did not exceed the values of admissible average annual activity for people established by NRB-99 and equal to 200 Bq/m^3.

2.5.4. Forecasted changes in radionuclide pollution of air basin

Theoretical estimations of the concentration of natural and artificial radionuclides in the air made for the STS "northern" territories show that transboundary transfer of radioactivity beyond the test sites with area contamination is insignificant and is not hazardous either now or in future [1]. The results of theoretical estimations of the air basin of the STS "western" areas enable to make the same conclusion.

Moreover, radionuclides migrate with time to a higher depth in the soil layer, so radionuclide pollution caused by wind transfer goes down to minimal values. Therefore, radioecological parameters of the air basin of the studied area may only get better.

2.6. State of vegetation cover

2.6.1. Concentration of natural radionuclides in the vegetation of the studied area

Concentration of artificial radionuclides in vegetation of studied area was estimated based on average values of accumulation coefficients (C_t) for ^{40}K, ^{232}Th and ^{226}Ra, taken from the IAEA materials ("Quantitative Parameters of Radionuclide Transfer in Surface and Freshwater Environment for Radioecological Assessment" (2009)) [28] and experimental data for the STS northern part presented in the "Materials of Complex Investigation of the STS "Northern" Areas" [1] and C_a for ^{40}K, ^{232}Th and ^{226}Ra calculated on the base of specific activities of radionuclides in soils and vegetation (steppe motley grass) sampled on the studied STS area covered with steppe vegetation (2000-2005). Average values of C_t for ^{40}K, ^{232}Th and ^{226}Ra are presented in Table 20.

Table 20.

Average C_t values for radionuclides in some groups of vegetation

Plants	C_a		
	^{40}K	^{232}Th	^{226}Ra
Studied area			
Motley grass	0.4 (n=5)	0.2 (n=5)	0.2 (n=5)
STS territory			
Motley grass	0.6 (n=171)	0.2 (n=92)	0.3 (n=118)
(in brackets – number of cases)			

The C_t values for ^{40}K, ^{232}Th and ^{226}Ra do not contradict either international or experimental data given in the "Materials of Complex Investigation of the STS "Northern" Areas" [1], and therefore they are further used in calculations of specific activities (SA) of the above radionuclides in plants (Table 21).

Table 21.

Calculation of specific activity of natural radionuclides in plants on the studied area

Average values	Natural radionuclides		
	^{40}K	^{232}Th	^{226}Ra
C_t	0.5	0.2	0.25
SA in soil, Bq/kg	685	29	26
SA in plants, Bq/kg	342.5	5.8	6.5

According to the results of calculations the highest concentration is observed for ^{40}K as one of the most widely spread radionuclides, which in its turn is one of the main sources of natural radioactivity. Concentrations of ^{232}Th and ^{226}Ra in vegetation of the studied area are for 2 orders of magnitude lower than that of ^{40}K.

2.6.2. Type of contamination of vegetation cover with artificial radionuclides

To determine the type of contamination of vegetation cover of the STS western part by artificial radionuclides we studied levels and parameters of transfer of radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am, ^{151}Sm and ^{99}Tc from soil to vegetation. For 2 years field works on joint sampling of soil and vegetation for further C_a calculation for radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am were carried out. In 2009, in the places with elevated values of radionuclide specific activity in soil detected by previously obtained data (before 2009) 10 research sites (sampling points) were made. In each sampling point samples of soil (sampling area – 10×10 cm, to a depth of 5 cm) and top part of plants (sampling area ~ 2–4 m^2) were taken. The samples were presented by motley grass mainly including feather grass (*Stipa capillata*, *S. sareptana*, *S. lessingiana*), fescue (*Festuca valesiaca*) and wormwoods (*Artemisia gracileccens, A. frigida*). The obtain statistically more reliable C_a values for plants in the STS western part, in places where elevated concentrations of these radionuclides were detected in 2009, in these places we took 12 mixed samples of steppe motley grass and 12 soil samples. Sampling points on the studied area were chosen according to the results of studying of vegetation cover in 2009, and they cover the main geobotanical contours – granite low hills, high ridged hills, low hills, deluvial-proluvial valleys and anthropogenically-disturbed areas (Figure 19).

Specific activities of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am radionuclides were measured in soils and plants by gamma-spectroscopy (^{137}Cs and ^{241}Am) and radiochemistry (^{90}Sr и $^{239+240}$Pu). ^{137}Cs concentration in plants was determined in dry (preliminary washed) grinded samples, concentrations of ^{241}Am, ^{90}Sr and $^{239+240}$Pu were determined in ash with further re-calculation to the dry substance. In order to estimate parameters of radionuclide transfer from soil to vegetation we calculated C_t values – the ratio of radionuclide concentration in the unit of soil and plant mass, respectively [27]. The C_t values and specific activity of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in plant samples are presented in table 22.

Table 22.

Specific activity and C_t of radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in vegetation samples

Site No.	Specific activity of radionuclides in vegetation, Bq/kg				$К_п$			
	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}$Pu
1	<0.15	1.11±0.12	<1.8	<0.07	<0.26	0.06	<0.23	<0.08
2	<0.15	1.36±0.05	3.2±0.6	0.35±0.04	<0.26	0.14	<0.32	<0.60
3	<0.15	0.95±0.07	<2.1	<0.04	<0.45	0.04	<0.18	<0.01
4	<0.15	0.32±0.03	<1.7	0.15±0.03	<0.38	0.01	<0.23	0.04
5	<0.15	0.96±0.08	4.3±0.9	<0.06	<0.41	0.02	0.15	<0.02
6	<0.15	0.51±0.05	3.7±0.9	<0.22	<0.09	0.02	<0.27	<0.06
7	<0.15	0.86±0.11	<1.7	<0.05	<0.08	0.02	<0.12	<0.01
8	<0.15	0.86±0.16	<2.6	0.18±0.03	<0.15	0.01	<0.15	0.03
9	<0.15	0.67±0.07	<2.1	0.18±0.04	<0.30	0.15	<0.20	0.12
10	<0.15	0.48±0.09	<2.3	<0.04	<0.12	0.03	<0.24	<0.001
11	<0.22	< 0.42	8.6±2.9	0.169± 0.047	<0.07	<0.04	<8.6*	0.002
12	<0.15	< 0.42	< 3.9	< 0.061	<0.07	<0.01	<1.95	<0.002
13	<0.27	< 0.47	5.2±1.9	0.167± 0.042	<0.02	<0.01	<5.2*	0.003
14	<0.15	< 0.24	< 3.8	0.082± 0.037	<0.15	<0.004	<1.9	0.004
15	<0.15	< 0.47	< 3.9	0.214±0.054	<0.15	<0.02	<1.95	0.01
16	<0.27	< 0.39	8.9±2.9	< 0.056	<0.10	<0.04	0.56	<0.05
17	<0.15	< 0.42	< 5.3	0.212±0.041	<0.15	<0.02	<0.19	0.05
18	<0.35	< 0.56	10.4±2.0	0.090±0.041	<0,12	<0,01	1,73	0,01
19	<0.15	< 0.31	7.3±4.0	0.130± 0.033	<0,07	<0,01	<3,65*	0,01

Site No.	Specific activity of radionuclides in vegetation, Bq/kg				K_n			
	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}$Pu
20	<0.31	< 0.39	8.8±2.8	0.066± 0.033	<0,19	<0,01	<4,4*	0,01
21	<0.28	0.60±0.29	7.8±2.2	0.309±0.049	<0,38	0,02	<3,9*	0,21
22	<0.25	4.38±0.43	9.1±4.2	0.306±0.051	<0,17	0,1	<4,55*	0,05
Average values of Kn					**	0.05	0.81	0.04
* - specific activity of the radionuclide in soil for this site is below the determination threshold ** - average assessed value of Kn^{241}Am - <0.20								

The above analysis showed that maximal values of ^{137}Cs specific activity in plants of the STS western part do not exceed ~4 Bq/kg, ^{90}Sr ~10 Bq/kg, $^{239+240}$Pu ~0,3 Bq/kg, ^{241}Am – are below the detection limit.

As the average accumulation coefficients of ^{137}Cs and $^{239+240}$Pu we took the values based on experimental data obtained for motley grass of the studied area in 2009–2010, for ^{90}Sr we used experimental materials of the Institute presented in the "Materials of Complex Investigation of the STS "Northern" Areas" [1]. The average accumulation coefficients for ^{241}Am, ^{151}Sm and ^{99}Tc were taken from the IAEA data (2009) [28]. Taking into account the accepted C_t values and average values of radionuclides specific activity (SA) in soil on all the territory and in the zone with elevated concentrations of some elements we calculated average concentrations of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am, ^{151}Sm and ^{99}Tc in plants (Table 23).

Table 23.

Calculation of specific activity of artificial radionuclides in vegetation in the studied area

Average values	Artificial radionuclides					
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{151}Sm	^{99}Tc
C_a	0.05	0.7	0.04	0.01	0.5	5
Average SA in soil, Bq/kg	18	6	6.5	1.1	1.4	0,3
Average maximal SA in soil, Bq/kg	29	-	22	3.7	-	-
Calculated SA in plants, Bq/kg	0.9	4.2	0.26	0.011	0.7	1.5
Calculated SA in plants (average maximal), Bq/kg	1.45	-	0.88	0.037	-	-
Admissible levels in plants, Bq/kg	74	111	~10*	~10*	~1,000*	~1,000*
Note: * – supposed admissible levels, see below.						

As a whole, the results of calculations do not contradict the analytical data – the average values of calculated specific activity of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am in plants on all studied area are lower than concentrations of the above radionuclides in plants samples in the places with elevated level of soil contamination.

The assumed concentration of radionuclides ^{137}Cs and ^{90}Sr in plants does not exceed maximum permissible levels of radioactive contamination of fodder crops (^{137}Cs – 74 Bq/kg, ^{90}Sr – 111 Bq/kg), established by the Ministry of Agriculture of the Republic of Kazakhstan (1994) [29].

Specific activity of radionuclides $^{239+240}Pu$, ^{241}Am, ^{151}Sm and ^{99}Tc in plants is not normalized, however, based on general radiotoxicity of elements, one can suppose that permissible levels for $^{239+240}Pu$ and ^{241}Am will be an order of magnitude lower and levels for ^{151}Sm and ^{99}Tc will be an order higher than that for ^{90}Sr [30]. It should be noted that the assumed permissible levels in plants for all the above-listed radionuclides are much higher than the average calculated levels of specific activity in them.

2.6.3. Quality assessment and forecasted changes in radionuclide contamination of vegetation cover

Vegetation of the studied area is mainly presented by the vegetation of dry steppes. The concentration of artificial radionuclide ^{137}Cs does not exceed 6%, ^{90}Sr – 10 % of the maximum permissible levels [29]. The concentration of $^{239+240}Pu$, ^{241}Am and ^{99}Tc in plants is less than 1%, the concentration of ^{151}Sm is less that 0.1% of maximum permissible levels. No anomalously high values of specific activity of natural radionuclides were detected in plants on the studied area.

Radionuclide contamination of vegetation primarily depends on susceptibility of plants to accumulation of radionuclides and on the accessibility of radionuclides determined by soil characteristics. "Fresh" radionuclides, after getting into soil, are more accessible for plants than in later time periods when radionuclides have reached their equilibrium state. The intensity of this process depends on physical-chemical properties of radionuclides. For example, the amount of ^{137}Cs absorbed by plants considerably decreases with time, whereas ^{90}Sr mobility in the soil-plant system varies slowly [31]. These facts enable to forecast possible decrease in the radionuclide contamination of vegetation in future than its increase.

Therefore, the vegetation of the studied area, in terms of type of its contamination, both now and in the far future presents no hazard for people and can be considered suitable for economic use (including pasturing of domestic animals).

2.7. Assessment of the radiological state of animal world. Forecasted changes in the radionuclide contamination of animals.

Of 46 mammal species inhabiting on the studied area 11 refer to the objects of amateur hunting, 9 of which are objects of food hunting. Of 147 bird species 22 are objects of amateur hunting, 18 species are objects of game hunting and 28 are used for other purposes (besides hunting). 3 species of 7 reptile species are used for other purposes (besides hunting) [32].

In examinations of the STS western part radionuclide analyses of three water birds were made. Of the birds one species, teal, is a food bird of a rather high demand. Tasty meat, wide areal and high population make it one of the most common objects of sports hunting [32]. The other species – bald-coot is not an object of food hunting but an object of sports hunting and can be used as food.

The results of gamma-spectrometry showed that concentration of ^{137}Cs, whose accumulation in muscle bulk of animals is more probable than accumulation of other radionuclides was not above the quantitative level in any samples. According to SAnPiN the admissible level for ^{137}Cs in fowl meat is 320 Bq/kg [33].

Concentration of radionuclides in meat of some species of wild animals was estimated in investigations of STS "northern" areas [1]. In those areas prognosis values calculated based on average values of radionuclides concentrations in soils of STS "northern" areas were much lower than permissible values. For example, maximal predicted radionuclide concentration in meat of wild animals was 0.44 and 0.008% for ^{137}Cs and ^{90}Sr, respectively. In case the territory of site "4A", having elevated ^{137}Cs and ^{90}Sr concentrations in the soil-vegetation cover, were included in the pasturing zone the prognosis concentrations of these radionuclides in meat of wild animals – 6.5 and 5.3%, respectively – did not exceed the permissible values. The estimated values for concentrations of the radionuclides $^{239+240}$Pu and ^{241}Am did not exceed 0.0003 and 0.002% of the permissible levels.

Forecasted values of specific activity of radionuclides in meat of wild animals do not exceed permissible levels for radionuclide concentrations in foodstuffs [33].

2.8. Theoretical assessment of the levels of contamination in crop and stock-farm products

As the studied area does not have objects where agricultural works are carried out, radiation characteristics of products produced on the territory of the studied area were estimated by calculations based on average values of radionuclide concentration in soil of the studied area and coefficients (C_t) of radionuclide transfer into different types of crop products.

To estimate radionuclide concentration in hay we used coefficients (C_t) for $^{239+240}$Pu and ^{137}Cs transfer from soil to steppe motley grass obtained in the investigations made in the STS northern part (Table 24). C_t for ^{90}Sr and ^{241}Am were taken from the IAEA data [28].

Table 24.

Coefficients of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu and ^{241}Am transfer into steppe motley grass

Radionuclide	N	C_t	Radionuclide	N	C_t
^{137}Cs	12	5*10^{-2}	$^{239+240}$Pu	12	4*10^{-2}
^{90}Sr	106	7*10^{-1}	^{241}Am	*	1*10^{-2}
*Note – C_t are taken from the IAEA materials [28]					

Radionuclide migration into agricultural crop products on the STS territory was not studied, therefore to estimate possible radionuclide concentrations in crop products we used C_t accepted for estimations in northern areas based on maximal published C_t values [1] (Table 25).

Table 25.

Coefficients of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu and ^{241}Am transfer into crop products used in prognosis calculations

Type of products	C_t			
	^{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 resources				
Hay (motley grass)	5.0*10^{-2}	7.0*10^{-1}	4.0*10^{-2}	1.0*10^{-2}

Type of products	C_t			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Corn	2.9*10^{-1}	4.0*10^{-1}	3.0*10^{-6}	2.9*10^{-1}
Leafy vegetables				
Cabbage, spinach, leafy celery, lettuce	1.8*10^{-1}	2.0	2.8*10^{-4}	2.4*10^{-4}
Legumes				
Peas, beans	4.3*10^{-2}	1.5	6.7*10^{-5}	4.8*10^{-4}
Fruit vegetables				
Tomatoes, cucumbers, pepper, aubergine	9.4*10^{-2}	1.5	8.5*10^{-5}	7.9*10^{-4}
Tuber plants				
Potato	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}

In preparing materials of complex survey the following values of average specific radionuclide activities in soils (0-5cm layer) of the studied area were used: for ^{137}Cs – 18, for ^{90}Sr – 6, for $^{239+240}$Pu – 6.5, for ^{241}Am – 1.1 Bq/kg. These values were used in calculations of radionuclide concentrations in crop products. As coefficients of radionuclide transfer into vegetables were obtained for the soil layer of 0-20cm (except steppe motley grass) [1], radionuclide specific activity was calculated in the 0-20cm soil layer. The obtained average values of soil specific activity (0-20cm layer) were: for ^{137}Cs – 4.6, for ^{90}Sr – 1.8, for $^{239+240}$Pu – 1.6 and for ^{241}Am – 0.3 Bq/kg.

The values of radionuclide concentrations in crop products were calculated for dry mass of crop products, therefore to recalculate them for wet mass the data on percentage content of dry mass in plants given in the IAEA materials [28] were used.

The radionuclide concentration is calculated by the formula:

$$C_{prognos} = C_{soil} \times C_t \times \frac{C_{\%}}{100} \quad ,$$

where $C_{prognos}$ is the prognosis concentration (Bq/kg);

C_{soil} is the average radionuclide concentration in soil (Bq/kg);

Ct is a transfer coefficient;

$C_{\%}$ is concentration of dry substance in the total plant mass (in %).

Table 26 presents the values of calculated radionuclide concentrations in crops products (per wet mass) in case of their production on the studied area and permissible radionuclide concentrations in crops products according to SanPiN 4.01.071.03 [33]. Concentrations of radionuclides $^{239+240}$Pu and ^{241}Am in foodstuffs is not regulated, however, as in NRB-99 (Appendix P-2) the limit of annual intake with food for people is an order of magnitude lower than the value for ^{90}Sr ($^{239+240}$Pu –2.4*10^3, ^{241}Am – 2.7*10^3, ^{90}Sr – 1.3*10^4 Bq/kg), and taking into account their higher radiotoxicity one can assume that their permissible levels will be an order lower than for ^{90}Sr [30]. Permissible levels for $^{239+240}$Pu and ^{241}Am presented in table 26 were obtained from the above calculation.

Table 26.

Expected radionuclide concentrations in crops products (per wet mass) in case of their production on the studied area (calculation is based on average radionuclide concentrations in soil of the studied area)

Type of product	Prognosis and permissible specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Grain crops				
Rye	4.4*10^{-1} (70)	2.5*10^{-1} (40)	2.2*10^{-5} (4.0)	4.1*10^{-3} (4.0)
Wheat	4.5*10^{-1} (70)	2.5*10^{-1} (40)	6.7*10^{-5} (4.0)	4.1*10^{-3} (4.0)
Barley	6.9*10^{-1} (70)	2.5*10^{-1} (40)	6.7*10^{-5} (4.0)	4.1*10^{-3} (4.0)
Oats	8.5*10^{-1} (70)	2.5*10^{-1} (40)	6.7*10^{-5} (4.0)	4.1*10^{-3} (4.0)
Fodder crops				
Hay (motley grass)	7.7*10^{-1} (74*)	3.6 (111*)	2.2*10^{-1} (11.1)	9.4*10^{-3} (11.1)
Corn	1.1 (70)	6.1*10^{-1} (40)	4.2*10^{-6} (4.0)	6.8*10^{-2} (4.0)
Leafy vegetables				
Cabbage	1.0*10^{-1} (600)	4.3*10^{-1} (200)	5.5*10^{-5} (20)	7.9*10^{-6} (20)
Spinach	6.7*10^{-2} (600)	2.9*10^{-1} (200)	3.7*10^{-5} (20)	5.3*10^{-6} (20)
Leafy celery, lettuce	5.0*10^{-2} (600)	2.1*10^{-1} (200)	2.7*10^{-5} (20)	4.0*10^{-6} (20)
Legumes				
Beans, peas	1.7*10^{-1} (50)	2.3 (60)	9.3*10^{-5} (6,0)	1.1*10^{-4} (6,0)
Fruit vegetables				
Tomatoes, pepper, aubergine	2.6*10^{-2} (600)	1.6*10^{-1} (200)	8.3*10^{-6} (20)	1.3*10^{-5} (20)
Cucumbers	2.2*10^{-2} (600)	1.3*10^{-1} (200)	6.9*10^{-6} (20)	1.1*10^{-5} (20)
Tuber plants				
Potato	1.3*10^{-1} (120)	4.5*10^{-1} (40)	3.4*10^{-4} (4.0)	5.3*10^{-5} (4.0)
Beet (roots)	9.7*10^{-2} (600)	3.7*10^{-1} (200)	4.4*10^{-4} (20)	3.8*10^{-5} (20)
Carrot (roots)	8.5*10^{-2} (600)	3.2*10^{-1} (200)	3.9*10^{-4} (20)	3.3*10^{-5} (20)
Note: * – admissible levels 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) [29].				

As a result of studying of area radionuclide distribution in soil cover of the studied area the zone of elevated specific activity of radionuclides ^{137}Cs, $^{239+240}$Pu and ^{241}Am was detected. The average values of specific activities in the zone were ^{137}Cs – 29, $^{239+240}$Pu – 22 and ^{241}Am – 3.7 Bq/kg. Table 27 presents the values of prognosis radionuclide concentration in crop products (per wet mass) in case of their production on the studied area.

Table 27.

Expected radionuclide concentrations in crops products (per wet mass) in case of their production in the zone of elevated activities of artificial radionuclides (calculation is based on average radionuclide concentrations in soil)

Type of products	Prognosis and permissible specific activity, Bq/kg		
	^{137}Cs	$^{239+240}$Pu	^{241}Am
Grain crops			
Rye	7.2*10^{-1} (70)	2.2*10^{-4} (4.0)	1.4*10^{-2} (4.0)

Type of products	Prognosis and permissible specific activity, Bq/kg		
	^{137}Cs	$^{239+240}$Pu	^{241}Am
Wheat	$7.2*10^{-1}$ (70)	$2.3*10^{-4}$ (4.0)	$1.4*10^{-2}$ (4.0)
Barley	1.1 (70)	$2.2*10^{-4}$ (4.0)	$1.4*10^{-2}$ (4.0)
Oats	1.4 (70)	$2.2*10^{-4}$ (4.0)	$1.4*10^{-2}$ (4.0)
Fodder crops			
Hay (motley grass)	1.2 (74)	$7.5*10^{-1}$ (11.1)	$3.1*10^{-2}$ (11.1)
Corn	1.8 (70)	$1.4*10^{-5}$ (4.0)	$2.3*10^{-1}$ (4.0)
Leafy vegetables			
Cabbage	$1.6*10^{-1}$ (600)	$1.9*10^{-4}$ (20)	$2.7*10^{-5}$ (20)
Spinach	$1.1*10^{-1}$ (600)	$1.2*10^{-4}$ (20)	$1.8*10^{-5}$ (20)
Leafy celery, lettuce	$8.1*10^{-2}$ (600)	$9.3*10^{-5}$ (20)	$1.3*10^{-5}$ (20)
Legumes			
Beans, peas	$2.7*10^{-1}$ (50)	$3.1*10^{-4}$ (6.0)	$3.8*10^{-4}$ (6.0)
Fruit vegetables			
Tomatoes, pepper, aubergine	$4.2*10^{-2}$ (600)	$2.8*10^{-5}$ (20)	$4.4*10^{-5}$ (20)
Cucumbers	$3.5*10^{-2}$ (600)	$2.3*10^{-5}$ (20)	$3.7*10^{-5}$ (20)
Tuber plants			
Potato	$2.0*10^{-1}$ (120)	$1.1*10^{-3}$ (4.0)	$1.8*10^{-4}$ (4.0)
Beet (roots)	$1.6*10^{-1}$ (600)	$1.5*10^{-3}$ (20)	$1.3*10^{-4}$ (20)
Carrot (roots)	$1.4*10^{-1}$ (600)	$1.3*10^{-3}$ (20)	$1.1*10^{-4}$ (20)

In order to estimate radionuclide concentration in stock-farming products, like in crop products, transfer coefficients (ratio of radionuclide concentration in stock-farming products to daily intake with ration) are used.

In prognosis we used C_t used in estimation of the STS "northern" territories chosen on the base of analysis of both literature data and our own investigations [1]. In order to predict radionuclide concentration we used the highest C_t values for different types of crop products found in literature – for radionuclides ^{137}Cs and ^{90}Sr in mutton we used maximal C_t values obtained during STS experiments. For mare's meat and milk no C_t values were found in literature, so we took C_t values used for cattle.

In estimating radionuclide concentration in stock-farming products we took into account their specific activity in ration and coefficients C_t of their transfer from ration into products. The radionuclide concentration in stock-farming products (C_{prod}) is calculated by the formula:

$$C_{prod} = C_{rat} \times Ct\,,$$

where: C_{rat} is radionuclide activity in daily ration, Bq;

C_t is the coefficient of radionuclide transfer from ration to 1l (kg) of products.

The average daily intake with the ration was a sum of the following parameters: radionuclide intake with fodder, intake with soil particles on plants and intake with swallowed soil from the ground surface.

To calculate radionuclide intake with soil particles on fodder (dust), the amount of soil particles on plants was determined experimentally. For this purpose, wash-outs from the dominant steppe plants (19 wash-outs) were made. The average volumes of soil particles from 1 kilogram of dry mass for different types of plants were different: for fescue – 10.1g, for wormwood – 11.6g, wild wheat – 6.2g, feather-grass – 5.1g. As a result, in calculations of radionuclide intake with vegetation dust we took the average value for motley grass – 8.1g/kg obtained using all available data.

Daily radionuclide intake with soil swallowed by animals during pasturing was calculated as during pasturing period cattle can intake up to 600kg of soil, sheep and goats can intake up to 75 kg of soil [34, 35]. Therefore, daily soil intake for horses was 1.78kg, for sheep and goats – 0.22kg.

Based on the above data and calculated radionuclide concentration in fodder obtained based on the average values of radionuclide concentration in soil (grassland steppe) and daily intake of pasture grass [36], the value of daily radionuclide intake by animals was calculated. The results are presented in table 28.

Table 28.

Results of calculation of possible radionuclide intake by domestic animals on the studied area (based on the average values of radionuclide concentration in soil)

Domestic animals	Average mass, kg	Daily intake of pasture grass,(per dry weight), kg	Intake of radionuclides by 1 animal, Bq							
			^{137}Cs				^{90}Sr			
			Daily intake with fodder (without account for dust)	Daily intake with plant dust	Daily intake with soil	Total daily intake	Daily intake with pasture grass (without account for dust)	Daily intake with plant dust	Daily intake with soil	Total daily intake
Horse	350-400	18	13.8	2.6	32.1	48.6	6.4	0.9	10.7	18.0
Cow	400	16	12.2	2.3	32.1	46.7	5.7	0.8	10.7	17.2
Sheep	50-60	2.5	1.9	0.4	4.0	6.3	0.9	0.1	1.3	2.4
Goat	50-60	2	1.5	0.3	4.0	5.8	0.7	0.1	1.3	2.2
Poultry	4-6	0.1*	0.04	-	-	0.04	0.03	-	-	0.03
Intake of transuranium radionuclides										
			$^{239+240}$Pu				^{241}Am			
Horse	350-400	18	4.0	1.0	11.6	16.5	0.2	0.2	2.0	2.3
Cow	400	16	3.5	0.8	11.6	16.0	0.1	0.1	2.0	2.3
Sheep	50-60	2.5	0.5	0.1	1.5	2.1	0.02	0.02	0.2	0.3
Goat	50-60	2	0.4	0.1	1.5	2.0	0.02	0.02	0.2	0.3
Poultry	4-6	0.1*	$6.7*10^{-6}$	-		$6.7*10^{-6}$	$4.1*10^{-4}$	-	-	$4.1*10^{-4}$
*Note: Daily intake for poultry is given for dry wheat (grain) weight										

Table 29 presents the values of calculated radionuclide concentrations in stock-farming products in case of their production on the studied area and permissible radionuclide concentrations in stock-farming products according to SanPiN 4.01.071.03 [33]. Permissible concentrations of $^{239+240}$Pu and ^{241}Am in stock-farming products were calculated as for crop products.

Table 29.

Estimated values of radionuclide specific activity in stock-farming products in case of their (calculation is based on average radionuclide concentrations in soil)

Type of product	Estimated concentration, Bq/kg (permissible concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Horse				
milk (kumys)	1.12(100)	5.05*10^{-2} (25)	1.65*10^{-4} (2.5)	9.63*10^{-7} (2.5)
meat (horseflesh)	2.48 (160)	1.44*10^{-1} (50)	9.92*10^{-4} (5.0)	1.15*10^{-3} (5.0)
Cattle				
Milk	1.07 (100)	4.82*10^{-2} (25)	1.60*10^{-4} (2.5)	9.48*10^{-7} (2.5)
Meat (beef)	2.38 (160)	1.38*10^{-1} (50)	9.59*10^{-4} (5.0)	1.13*10^{-3} (5.0)
Sheep				
Milk	4.85*10^{-1} (100)	1.32*10^{-1} (25)	2.14*10^{-4} (2.5)	-
Meat (mutton)	1.45(160)	2.59*10^{-4} (50)	1.13*10^{-4} (5.0)	3.20*10^{-5} (5.0)
Goat				
Milk	7.59*10^{-1} (100)	6.02*10^{-2} (25)	-*	1.95*10^{-6} (2.5)
Meat	2.80 (160)	6.45*10^{-3}(50)	-	-
Poultry				
Meat	5.4 (180)	2.01*10^{-3} (80)	-	-
Eggs	2.02*10^{-2} (80)	2.21*10^{-2} (50)	-	-
Note: * - no estimated values are given as no C_t data are available				

Table 30 gives possible radionuclide intake by domestic animals in case of their pasturing in the zone of elevated concentrations of radionuclides ^{137}Cs, $^{239+240}$Pu and ^{241}Am on the studied area.

Table 30.

Results of calculation of possible radionuclide intake by domestic animals in case of their pasturing in the zone of elevated concentration on the studied area (based on the average values of radionuclide concentration in soil of the zone of elevated radiation)

Domestic animals	Average mass, kg , кг	Daily intake of pasture grass,(per dry weight), kg	Radionuclide intake by 1 animal, Bq/kg											
			^{137}Cs				$^{239+240}$Pu				^{241}Am			
			Daily intake with fodder (without account for dust)	Daily intake with plant dust	Daily intake with soil	Total daily intake	Daily intake with fodder (without account for dust)	Daily intake with plant dust	Daily intake with soil	Total daily intake	Daily intake with fodder (without account for dust)	Daily intake with plant dust	Daily intake with soil	Total daily intake
Horse	350-400	18	22.2	4.3	51.8	78.2	13.6	3.2	39.3	56.0	0.6	0.5	6.6	7.7
Cow	400	16	19.7	3.8	51.8	75.3	12.0	2.9	39.3	54.1	0.5	0.5	6.6	7.6
Sheep	50-60	2.5	3.1	0.6	6.5	10.1	1.9	0.4	4.9	7.2	0.08	0.07	0.8	1.0
Goat	50-60	2	2.5	0.5	6.5	9.4	1.5	0.4	4.9	6.8	0.06	0.06	0.8	0.9

Specific activities of stock-farming products in case of animals' pasturing in the zone of elevated concentrations of radionuclides on the studied territory were calculated (table 31).

Table 31.

Estimated values of specific radionuclide activity in stock-farming products in case animals are pastured in the zone of elevated radiation on the studied area (based on the average values of radionuclide concentration in soil of the zone)

Type of product	Estimated and permissible specific activity, Bq/kg		
	^{137}Cs	$^{239+240}$Pu	^{241}Am
Horse			
milk (kumys)	1.80(100)	$5.60*10^{-4}$ (2.5)	$3.24*10^{-6}$ (2.5)
meat (horseflesh)	3.99 (160)	$3.36*10^{-3}$ (5.0)	$3.86*10^{-3}$ (5.0)
Cattle			
Milk	1.73 (100)	$5.41*10^{-4}$ (2.5)	$3.19*10^{-6}$ (2.5)
Meat (beef)	3.84 (160)	$3.25*10^{-3}$ (5.0)	$3.80*10^{-3}$ (5.0)
Sheep			
Milk	$7.81*10^{-1}$ (100)	$7.20*10^{-4}$ (2.5)	-
Meat (mutton)	2.33(160)	$3.82*10^{-4}$ (5.0)	$1.08*10^{-4}$ (5.0)
Goats			
milk	$7.59*10^{-1}$ (100)	-*	$6.55*10^{-6}$ (2.5)
meat	2.80 (160)	-	-
Poultry			
Meat	5.4 (180)	-	-
Eggs	$2.02*10^{-2}$ (80)	-	-
Note: * - no estimated values are given as no C_t data are available			

The investigations have shown that in agricultural products, both crops and stock-farming products, produced on the STS western territory radionuclide concentrations will not exceed the established standards in spite of the fact that the most conservative parameters values were used in calculations.

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

Economic use of radioactively contaminated areas may cause risk of radiation exposure of local people. The sources of radiation exposure may be radioactively contaminated environmental objects as well as foodstuffs produced on radioactively contaminated areas. Artificial radionuclides penetrating into human organism with inhaled air, water and food additionally contribute to the expected annual effective dose, which characterizes the degree of radiation hazard of the studied area. To estimate radiation doses we considered all ways of human exposure and chose those which make a considerable contribution to the annual effective dose taking into account living conditions, specificity of nutrition and work conditions. The descriptions of the above conditions formed different scenarios of human activities. According to preliminary estimations the highest risk of exposure of local people arises when a person lives and works on the studied territory, produces foodstuffs and eats them. Such a scenario is conventionally called "a farmer with subsistence farming" [37]. This approach enables to give a conservative assessment of the expected annual effective dose of people living and working on the STS western territory.

A measure of radiation risk is the expected annual effective dose of artificial radiation, which must not exceed 1 mSv per year for people according to NRB-99 [30].

In calculations of expected annual effective dose for local people, this work does not take into account natural radiation including:

external radiation exposure caused by cosmic radiation;

external and internal radiation exposure caused by daughter products of radon and thoron;

external and internal radiation exposure caused by natural radionuclide in soil surface layer.

To simplify the estimation of radiation exposure the following assumptions were made:

- the calculations did not take into account the decrease in the intensity of external radiation exposure, when soil was covered with snow (winter period) and when means of individual protection were used;
- the calculations did not take into account changes in air dustiness in different seasons of the year were not taken into account;
- the calculations did not take into account the increase in the distance from the ground (1.5-2 meters) and screening by the equipment (for farmer) or horse body in case of living and working on the STS western territory;
- the calculations did not take into account the internal radiation exposure caused by drinking water from local wells as the levels of specific activity of artificial

radionuclides in water is below the detection limits of used devices: for ^{137}Cs, ^{90}Sr it is < 002 Bq/kg, for $^{239+240}Pu$< 0.001, for ^{3}H< 15 Bq/kg, which, according to NRB-99, is 1-3 orders of magnitude below the intervention levels for drinking water;

- the calculations did not take into account the internal radiation exposure caused by not-local foodstuffs.

It is supposed that radioactive contamination is distributed uniformly over the area and exponentially in the soil horizon.

According to NRB-99, the exposure coefficients used to estimate doses when radionuclides penetrate with air are not subdivided into age groups.

Preliminary estimations of radionuclide concentrations in the surface soil layer on the studied territory by average values of specific activity give: ^{238}Pu – 0.1; ^{241}Pu – 3.1; $^{239+240}Pu$ – 6.5 Bq/kg. As exposure coefficients for ^{241}Pu are 2–4 orders of magnitude lower than coefficients for $^{239+240}Pu$ for different types of exposure for local people, ^{241}Pu was not taken into account. Exposure coefficients for ^{238}Pu are of the same order as coefficients for $^{239+240}Pu$, therefore in exposure calculations $^{238+239+240}Pu$ isotopes were used.

As specific activity and exposure coefficients of radionuclides ^{99}Tc (0.3 Bq/kg) and ^{151}Sm (1.4 Bq/kg) are 1–2 orders of magnitude lower than specific activity and exposure coefficients of ^{90}Sr, in estimation of radiation exposure the expected contribution of ^{99}Tc and ^{151}Sm will be less than 1%. Therefore in calculations of expected annual effective dose radionuclides ^{99}Tc and ^{151}Sm were not taken into account.

3.1. Choice of parameter values

3.1.1. Parameters used in calculations of radiation exposure

The results of investigations of the STS western territory showed that the surface soil layer contained the following dose-forming artificial radionuclides: ^{90}Sr, ^{137}Cs, $^{238+239+240}Pu$ and ^{241}Am. Experimentally determined average values of concentrations of artificial radionuclides in surface (5cm) soil layer and values for the zones with elevated concentrations of artificial radionuclides on the studied STS territory are presented in table 32.

Table 32.

Specific and area activity of artificial radionuclides in the surface soil layer in the STS western part

^{137}Cs	^{90}Sr	$^{238+239+240}Pu$	^{241}Am
Average values of specific activity, Bq/kg			
18	6	6.5	1.1
Area radionuclide activity for average values of specific activity, Bq/m^2			
1,170	390	429	71.5
Elevated values of specific activity, Bq/kg			
29	6*	22.2	3.7
Area radionuclide activity for elevated values of specific activity, Bq/m^2			
1,885	390	1,443	240.5
Note: * - average values of radionuclide specific activity for all territory are used			

3.1.2. Choice of parameters for annual food intake and expected values of radionuclide specific activity in products

To estimate internal radiation exposure caused by foodstuffs produced on contaminated area, it is necessary to know the volume of annual food intake.

The standards of consumption of the main foodstuffs for different social groups of population, which make the minimal set of foodstuffs required to provide human life is stated in the Law of the Republic of Kazakhstan of 16 November 1999 No.474-I "On Cost of Living" [38].

The standards stated in the Law are only averaged quantities for the citizens of Kazakhstan and may differ considerably for different social layers. Therefore to estimate radiation exposure caused by foodstuffs produced on the studied area we took parameters of the food basket given in [1]. It contains answers of the local people to the following questions: main characteristics of their household, whether they h ad an orchard garden or not, types of works done on the STS territory, annual consumption of produced foodstuffs. The results of questioning showed that the volume and structure of nutrition of local people living on the STS territory differed from the minimal food basket by a higher fraction of meat-and-milk products. Based on the results of questioning and living conditions of local people we introduced changes in the standards of intake of the main foodstuffs that can be produced and used by local people on the studied area.

The values of radionuclide specific activity in stock-farming and crop products were calculated employing radionuclide transfer coefficients presented in IAEA documents [28]. Based on the transfer coefficients for stock-farming and crop products we calculated expected specific activities of radionuclides further used to estimate radiation exposure from intake of artificial radionuclides through food chains.

3.2. A scenario of local inhabitant behavior in the STS western part

In estimating radiation exposure (in case of populating of the STS western part), the agricultural scenario was considered.

3.2.1. An agricultural scenario

This scenario considers conditions of people life and work on the studied territory.

Farmer’s (shepherd’s) family has four members (adults – a farmer (shepherd) and housewife, two children – a 1-2-year-old child and a child of 7-12). They eat plant-growing and stock-farming products produced on the studied territory. The choice of this age group for children was the fact that the main foodstuffs for a 1-2-year-old child are milk products, the 7-12-year-old child was considered in terms of inhaled air and consumption of foodstuffs as a middle link.

Air dustiness in the living premises was considered for all age groups equal to 10^{-7} kg/m^3. The screening (house’s walls) coefficient was taken equal 0.4 [39].

The following types of activities are considered in the agricultural scenario:

The farmer is growing plants and makes hay on the land lot (farm) located not far from the place where he lives. It is supposed that some part of his working time the farmer cultivates the land and looks after plants, the rest part of the day he spends in his homestead land, in the yard looking after domestic animals and at home. The farmer’s exposure is calculated in the assumption that he spends 8 hours a day in the open air. Air dustiness during works in the field and in the homestead is taken equal to 10^{-6} kg/m^3. The farmer’s role is fulfilled only by an adult (a man or a woman). During farm works the intensity of breathing is taken equal to 5.6 m^3/h for an adult.

The shepherd goes pasturing at a distance of 10-15 km from the place he lives and looks after cattle in the stable. His working day, on average, lasts 10 hours in the open air, the rest time he spends in the house. Air dustiness during pasturing and looking after cattle is equal to 10^{-6} kg/m^3, in the house – 10^{-7} kg/m^3. The farmer’s role is fulfilled only by an adult (a man).

The housewife (a woman) does house work, works in the homestead and in the yard, looks after domestic animals. She spends in the open air 8 hours. Air dustiness is taken equal to 10^{-6} kg/m^3.

Children of 7-12 spend in the open air (playing) on average 8 hours a day. Air dustiness is taken equal to 10^{-6} kg/m^3.

1-2-year-old children spend in the open air on average 4 hours a day. Air dustiness is taken equal to 10^{-6} kg/m^3.

Generalized data on the time spent by people in the open air and in-house are given in table 33.

Table 33.

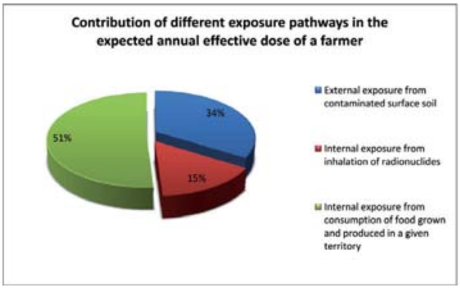
Time T spent in the open air and in-house

Factor	Units of measurement	Inhabitant scenario
		Value
Time spent in the open air	Hour/year	2,920 (farmer, housewife) 3,600 (shepherd) 2,920 (child of 7–12) 1,460 (child of 1–2)
Time spent in-house	Hour/year	5,840 (farmer, housewife) 5,160 (shepherd) 5,840 (child of 7–12) 7,300 (child of 1–2)

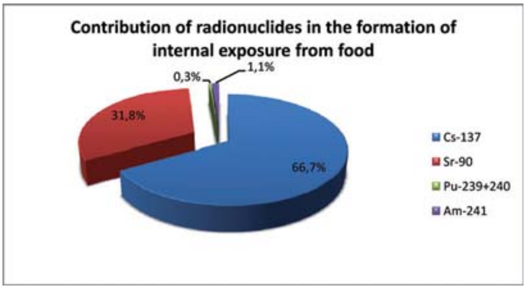
3.3. Results of estimation of radiation exposure of people living and working on the studied territory

Estimation of the radiation exposure of people living and working in the "western" part of the STS territory gave the following results.

The main contribution to the radiation exposure is caused by foodstuffs grown and produced on the studied territory. The internal radiation exposure caused by inhalation of contaminated dust particles is 15%, the external radiation exposure from the contaminated soil surface is 34% of the total annual effective dose (Figure 31).



a)



b)

Figure 31. a) Contribution of the main ways of farmer's exposure to the expected annual effective dose for average values of radionuclide specific activity in the surface soil layer;
b) Contribution of artificial radionuclides contained in foodstuffs grown and produced on the studied territory to internal radiation exposure

The main contribution to the radiation exposure by radionuclides is made by ^{137}Cs. The main contribution to the internal radiation exposure caused by inhalation of radionuclides is made by $^{238+239+240}$Pu (88 %).

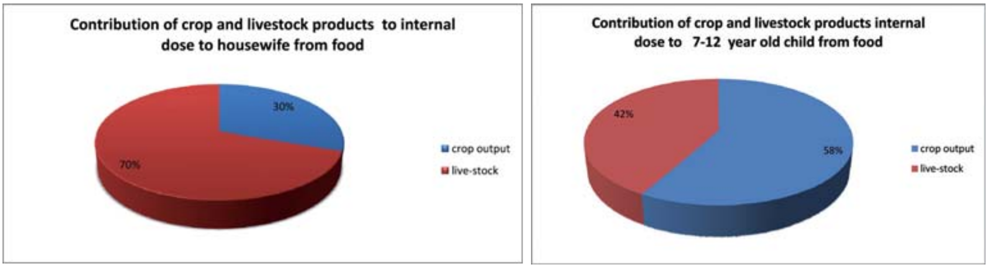
The main dose-forming radionuclides in foodstuffs are ^{137}Cs and ^{90}Sr. The figure and the table (figure 31, table 34) present the values of annual effective dose caused by intake of radionuclides ^{137}Cs and ^{90}Sr with foodstuffs which can be produced by people using western part of the STS territory.

Table 34.

Expected effective dose for a farmer and a 1-2-year-old child caused by intake of the main dose-forming radionuclides ^{137}Cs и ^{90}Sr with foodstuffs

Product type	Effective dose for average values of specific activity of radionuclides ^{137}Cs and ^{90}Sr, mSv/year			
	Farmer		1-2-year-old child	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Plant- growing products	$1.2 \cdot 10^{-3}$	$3.4 \cdot 10^{-3}$	$2.4 \cdot 10^{-4}$	$1.1 \cdot 10^{-3}$
Stock-farming products	$7.5 \cdot 10^{-3}$	$7.7 \cdot 10^{-4}$	$2.4 \cdot 10^{-3}$	$7.2 \cdot 10^{-4}$

The table shows that the main contribution to the plant-growing products is made by ^{90}Sr, to the stock-farming products – by ^{137}Cs. The contribution to the effective dose for an adult in case of intake with foodstuffs is 36% from plant-growing products and 64% from stock-farming products, for a 1-2-year-old child these figure are 29% and 71%, respectively. Figure 32 shows contribution of plant-growing and stock-farming products to the internal effective dose for a housewife and a 7-12-year-old child in case of radionuclides intake with foodstuffs. The main contribution to the expected effective dose from the stock-farming products for average specific activity of radionuclides in the surface soil layer is given by milk products – 50% for an adult and 96% for a 7-12-year-old child.



a) b)

Figure 32. Contribution of plant-growing and stock-farming products grown and produced on the studied area to the internal effective dose for a housewife (a) and a 7-12-year-old child (b)

Calculations of radiation exposure of people living and working on the western part of the STS territory gave the following results:

According to the agricultural scenario the expected annual effective dose for a farmer or a shepherd from intake of artificial radionuclides in the conditions of average specific activity of radionuclides in the surface soil layer does not exceed standards and is equal to ~$3.0\cdot10^{-2}$ mSv. Radiation exposure of a farmer or a shepherd for elevated values of specific activity of artificial radionuclides in the surface soil layer will make ~ $5.7\cdot10^{-2}$ mSv. The main contribution to the radiation exposure is made by the internal radiation exposure from foodstuffs – $1.3\cdot10^{-2}$ mSv.

According to the agricultural scenario the expected annual effective dose from intake of artificial radionuclides in the conditions of average specific activity of radionuclides in the surface soil layer will make $2.2\cdot10^{-2}$ mSv for the housewife, $1.9\cdot10^{-2}$ mSv for the 7-12-year-old child and $1.2\cdot10^{-2}$ mSv for the 1-2-year-old child. Radiation exposure in the conditions of elevated specific activity of radionuclides in the surface soil layer will make $3.9\cdot10^{-2}$ mSv for the housewife, $3.2\cdot10^{-2}$ mSv for the 7-12-year-old child and $1.9\cdot10^{-2}$ mSv for the 1-2-year-old child. According to the agricultural scenario the main contribution to the radiation exposure to artificial radionuclides is made by the internal radiation exposure from foodstuffs.

The main contribution of internal radiation exposure from intake of foodstuffs and external radiation exposure from the contaminated soil surface to the radiation exposure is made by ^{137}Cs. Radiation exposure from $^{238+239+240}$Pu and ^{241}Am for intake with foodstuffs and external radiation exposure is less than 1 %.

The above estimations of radiation exposure of people living and working on the studied territory showed that the expected annual effective dose will not exceed dose limits and will make less than 3% of maximal permissible values for people (1 mSv/year).

CONCLUSION

In 2009-2010 complex radiological investigations were carried out in the western part of the former Semipalatinsk Test Site of the total area of 560 km^2 located in Karaganda oblast. The subjects of investigations were environmental objects (soil-vegetation cover, water and air environment, animals). Additional investigations in 2009-2010 were carried out with account for radiological investigations done earlier on the territory.

As a result of investigations the following conclusions were made. The presence of artificial radionuclides in the environmental objects in the western part of the STS territory is mainly a result of global radioactive fallouts. Nowadays secondary radioactive contamination of the STS western part may be caused by local radioactively contaminated spots located on the test sites the "Experimental field" and "4", where radionuclide concentrations in soil-vegetation cover are comparable with solid radioactive wastes (SRW).

The radionuclide analysis of environmental samples showed that the average concentration of natural radionuclides in soils of the studied area is typical of Kazakhstani soils; no geochemical anomalies were discovered. The gamma-spectral analysis did not reveal the presence of any other radionuclides besides ^{137}Cs and ^{241}Am in any sample, in case there were the radionuclides ^{60}Co and ^{152}Eu, their amount was below the detection limits of used instrument, which means that they impose no danger on people and the environment. The radiochemical analysis of environmental samples enabled to determine concentration of such long-lived radionuclides as ^{90}Sr and $^{239+240}$Pu.

As a whole, the Areal distribution of radionuclides ^{137}Cs and ^{90}Sr is rather uniform. An analysis ^{241}Am Areal distribution revealed zones with elevated values of specific activity. The average values of specific activity of radionuclides ^{137}Cs and ^{90}Sr in the soils of the studied area are at the background level of global fallouts. Maximal values of specific activity of radionuclides ^{137}Cs and ^{90}Sr are below the levels characterizing ecological state of the area as "relatively satisfactory situation" according to the criteria of soil classification by the parameter of surface contamination with long-lived products of nuclear tests established by the Resolution of the RK Council of Ministers of 31 July 2007 "On Approval of Criteria to be Used to Assess Ecological Conditions of Territories". According to the criteria in terms of concentrations of radionuclide $^{239+240}$Pu in soils the surveyed areas refer to territories with "relatively satisfactory ecological situation".

Radionuclide concentrations in the vegetation cover of the studied area do not exceed the values established by the "Temporarily permissible levels of radionuclide concentrations in the objects of the Ministry of Agriculture of the Republic of Kazakhstan". As a whole, radionuclide concentrations in the vegetation cover of the studied area are not hazardous for people, and it can be used for different types of works (including pasturing of domestic animals) now and for an unlimited period of time in future.

The specific activity of artificial radionuclides in organisms of wild animals inhabiting in western part of the STS territory is at the acceptable level, even with account for migration from the nearest STS test sites. Estimated values of radionuclide concentrations in meat of wild food animals obtained in the investigations are much below the permissible values. Therefore eating meat of wild animals, the objects of hunting, is not dangerous and will not cause radiation exposure.

The materials prepared in this investigation enable to estimate radiation characteristics of products that can be produced on the territory of the studied area. Estimated values of specific activity of artificial radionuclides in plant-growing and stock-farming products are much lower than the maximal permissible level, even in case of their production in the zone of elevated values of specific activity of transuranium elements. Therefore the expected radionuclide concentration in the foodstuffs produced on the studied area will not exceed permissible levels according to Sanitary Rules and Norms No. 4.01.071.03 "Hygiene Requirements to Safety and Food Value of Foodstuffs" approved by the Resolution of the Ministry of Health of the Republic of Kazakhstan No.447 of 11 June 2003.

The results of investigations enable to conclude that according to the level of radionuclide concentration in ground and surface waters the STS western part can be used for any type of works without any limitations. Concentrations of radionuclides in waters of the studied area do not exceed the interference level for population for intake with water and food according to Radiation Safety Standards (NRB-99). Concentrations of radionuclides in the air of the studied area are not dangerous for people staying in the area. Radioactive contamination of the atmosphere may be hazardous only for a man directly staying on the territory of radiation-hazardous objects of the Test Site, and in case there is a large amount of dust in the air (dust storms, man-made dusting, etc.). At the same time transboundary transfer of radioactivity beyond the test sites and, moreover, beyond the Polygon territory is insignificant and not dangerous either now or in future.

Figure 33. A map of "western" territory recommended for transfer in economic use

A final conclusion on possibility of usage of the studied area for living and working is based on the estimations of radiation exposure of people who will further live in the area. Maximal permissible effective dose for man is 1 mSv/year. Estimation of expected radiation exposure in case of "the worst" scenario "a farmer with subsistence farming" on the contaminated area showed that expected annual effective dose per capita would not exceed 0.3mSv, which is below the interference level according to Radiation Safety Standards (Appendix 5, NRB-99).

Therefore the results of estimation of distribution of integral radiation parameters with account for acting requirements of the RK regulation base show that **all studied territory can be used without any limitations**.

A map of the territory recommended for transfer in economic use is given below (Figure 33).

When a territory is transferred in economic use, one must take into account that in order to control possible inflow of contaminated ground waters from the places of former nuclear tests to the ground waters of "western" territories and to detect the initial stage of any unfavorable tendencies in the development of the ecological situation it is necessary to organize additional observational hydrogeological posts, whose location is shown in chapter 2.4.3, and to connect them with the unified state monitoring system.

REFERENCES

1. Актуальные вопросы радиоэкологии Казахстана [Радиоэкологическое состояние "северной" части территории Семипалатинского испытательного полигона] / под рук. Лукашенко С.Н. – Вып. 1. – Павлодар: Дом печати, 2010. – 234с.: ил.- Библиогр.: С.224-231. - ISBN 978-601-7112-28-8.
   Topical issues in radio-ecology of Kazakhstan. [Radioecological conditions of "northern" part of STS lands] Issue 1 // ed by Lukashenko S.N. – Pavlodar: Printing house, 2010. 234 pp. - ISBN 978-601-7112-28-8. [in Russian]
2. Завершение 1 этапа радио-эколого-гео-химического обследования территории Карагандинской области, возвращаемой Семипалатинским ядерным полигоном: Отчет о НИР (заключительный) / ИРБЭ НЯЦ РК; Руководитель работы Ю.Г. Стрильчук - договор № 8 от 29.07.02, Инв. о-408.- Курчатов.- 2002.-101с.
   Completion of the 1st stage of radio-eco-geo-chemical surveying of Karaganda oblast lands returned back from Semipalatinsk nuclear test site: R&D Final Report//IRSE NNC RK; Works leader Strilchuk Yu.G. Contract No. 8 from 29.07.02 ##o-408. Kurchatov. – 2002, 101 pp. – [in Russian].
3. Информационный бюллетень. – Спецвыпуск. – 1993.
   Information bulletin. – Special edition. 1993. – [in Russian].
4. Ядерные испытания СССР. Семипалатинский полигон / под ред. В.А. Логачева – Москва: ИздАТ, 1997.
   Nuclear Tests in the USSR. Semipalatinsk Test Site // ed.by Logachev V.A. – Moscow: IzdAT, 1997. – [in Russian].
5. Бюллетень центра общественной информации по атомной энергии. – Спецвыпуск. – Москва, март, 1996. – С. 10.
   Bulletin of the Center for Public Information on Atomic Energy. – Special edition. Moscow, March 1996. 10pp. – [in Russian].

6. Сайбеков Т.С. Атлас. Радиационная обстановка на территории Республики Казахстан с 1954 по 1994 годы. Семипалатинская область / Т.С. Сайбеков, Ж.А. Абылаев. – Т. 16.– Алматы: Министерство экологии и биоресурсов РК, 1997. – 400 с.
   Saibekov T.S. Atlas. Radiological situation in the Republic of Kazakhstan 1954 – 1994. Semipalatinsk oblast.// Saibekov T.S., Abylayev Zh.A., V.16. – Almaty: Ministry of Ecology and Bioresourses RK, 1997. – 400pp. – [in Russian].
7. Материалы по вопросам радиоэкологического состояния территории бывшего СИП в результате воздействия значимых ядерных испытаний: окончательный доклад. Арзамас-16. – Москва, Санкт-Петербург, 1994.
   Materials on radioecological conditions at the territory of former STS due to considerable nuclear tests: final report. Arzamas-16. – Moscow, St.Petersburg, 1994. – [in Russian].
8. Андрюшин И.А. Ядерные испытания СССР. Гидроядерные эксперименты. Инвентаризация затрат плутония / И.А. Андрюшин, Н.П. Волошин, Р.И. Илькаев, А.М. Матущенко, В.Н. Михайлов, А.К. Чернышев [и др.] // Инф. бюлл. ЦНИИатоминформ.– 1998. – №12. – С. 60-63.
   Andriushin I.A. Nuclear tests in the USSR. Hydronuclear experiments. Inventory of plutonium consumption/ Andriushin I.A., Voloshin N.P., Ilkayev R.I., Matuschenko A.M., Mikhailov V.N. et al.// Inf.Bul. CRIAtominform. – 1998. - #12., pp 60-63. – [in Russian].
9. Логачев В. Радиоэкологические последствия испытаний БРВ на Семипалатинском полигоне / В. Логачев // Бюллетень по атомной энергии. – 2002. – №12.
   Logachev V. Radioecological consequences of WRA tests at Semipalatinsk test site.// Atomic Energy Bulletin. *– 2002. ##12.* – [in Russian].
10. Инструкция и методические указания по оценке радиационной обстановки на загрязненной территории. Госкомгидромет СССР. с 17.03.89 г.
   Instruction and methodic procedures for assessment of radiological situation at contaminated lands. Goscomhydromet USSR. From 17.03.1989. – [in Russian].
11. Методика выполнения измерений активности радионуклидов плутоний-238, плутоний-239+плутоний-240 в счетных образцах, приготовленных из проб объектов окружающей среды. Разработана ФГУП НПо Радиевый Институт им. В.Г. Хлопина.
   The method for activity measurements of Pu-238, Pu-239+240 radionuclides in samples prepared environmental samples. Developed by FSUE SPO V.G. Khlopin Radievyi Institute. – [in Russian].
12. Учебно-методическое руководство по радиоэкологии и обращению с радиоактивными отходами для условий Казахстана / ред. Т.Е. Каткова. - Алматы: ОАО "Волковгеология", 2002. - 304 с.
   Methodical aid on radioecology and handling of radioactive wastes in Kazakhstan/ ed.by. Katkov T.Ye. – Almaty: JSC "Volkovgeology", 2002. – 304 pp. – [in Russian].
13. Актуальные вопросы радиоэкологии Казахстана [Сборник трудов Института радиационной безопасности и экологии за 2007 – 2009 гг.] / под рук.

Лукашенко С.Н. – Вып. 2. – Павлодар: Дом печати, 2010. – 527с.: ил.- Библи-огр.: С.518. - ISBN 978-601-7112-32-5.
Topical issues in radio-ecology of Kazakhstan. Issue 2 // Proc. of IRSE for 2007-2009, ed by Lukashenko S.N. – Pavlodar: Printing house, 2010. 527 pp ISBN 978-601-7112-32-5. [in Russian]

14. Исаков К.И. Пастбища и сенокосы степной зоны / К.И. Исаков. – Алматы, 1993. - С. 38-42
Iskakov K.I. Pastures and hayfields of steppe zone // Almaty, 1993. pp. 38-42. – [in Russian].
15. Бельгибаев М.Е. Эколого-географические условия дефляции почв Северно-го и Центрального Казахстана / М.Е. Бельгибаев, Г.В. Зонов, Э.М. Паракши-на. – Алма-Ата, 1982. – С.15.
Belgibayev M.Ye. Ecologo-geographical conditions of soil deflation in northern and central Kazakhstan // Belgibayev M.Ye., Zonov G.V., Parakshina E.M. – Alma-Ata, 1982, p.15. – [in Russian].
16. Постановление Правительства РК от 31.07.2007 №653. Об утверждении критериев оценки экологической обстановки территорий. – Раздел 7.
Governmental Decree RK from 31.07.2007 #653 "About establishing the criteria for assessment of ecological conditions of lands" Part 7. – [in Russian].
17. СТ РК ГОСТ 51592-2003 "Вода. Общие требования к отбору проб".
RK State Standard GOST 51592-2003 "Water. General requirements to sampling". – [in Russian].
18. Методика определения содержания искусственных радионуклидов плутония-(239+240), стронция -90 и цезия-137 в природных водах методом концентрирования. – Алматы,2001г.
The method for determination of content of artificial radionuclides Pu-(239+240), Sr-90, Cs-137 in natural waters by the concentration. – Almaty, 2001. – [in Russian].
19. ISO 9698/1989 "Water quality. Determination of tritium activity concentration – liquid scintillation counting method".
СТ РК ГОСТ 26449.1-85 "Методы химического анализа солёных вод".
20. RK State Standard GOST 26449.1-85 "Methods of chemical analysis of saline waters". – [in Russian].
21. Санитарно-эпидемиологические правила и нормы РК №3.02.003.04
Sanitary and epidemiology rules and norms RK #3.02.003.04. – [in Russian].
22. Информационный отчет ИРБЭ НЯЦ РК за 2009. "Обеспечение безопасности бывшего Семипалатинского испытательного полигона". – Курчатов, 2009.
Information report of IRSE NNC RK for 2009. "Safety assurance at former Semipalatinsk test site". – Kurchatov, 2009. – [in Russian].
23. Комплексные исследования радиоактивного загрязнения системы атмосфера-подстилающая поверхность и оценки радиационных рисков для населения Семипалатинского региона. Технический отчет по проекту МНТЦ К-928. Руководитель Артемьев О.И. – Курчатов. – 2005-2006. Фонды ИРБЭ.

Complex investigations of radioactive contamination in the system atmosphere-underlying surface and assessment of radiological risks for population of Semipalatinsk region. Technical report on the ISTC Project K-928. // leaded by Artemiev O.I. – Kurchatov. – 2005-2006. IRSE database.
24. Oatway W. B. Methodology for Estimating The Doses to Member softhe Public fromthe Future Useof Land Previously Contaminated with Radioactivity / W. B. Oatwayand F. Mobbs // Report NRPB W36 National Radiological Protection Board Gteit Britanion, 2003.
25. Brown J andSimmonds JR. FARMLAND: A dynamicmodelforthetransferofradio nuclidestroughterrestrialfoodchains. Chilton, NRPB – R272. – 1995.
26. Рекомендация "Методика определения эксхаляции (плотности потока) радона с поверхности почв и грунтов с помощью прибора "Ramon-01" и его модификаций, Алматы, 1998.
Recommendation "The method for determination of radon exhalation from soil surfaces employing "Ramon-01" instrument and its modifications", Almaty, 1998. – [in Russian].
27. Гулякин И.В. Сельскохозяйственная радиобиология / И.В.Гулякин, Е.В. Юдинцева– М.: Колос, 1973. – 272 с.
Guliakin I.V. Agricultural radiobiology // Guliakin I.V., Yudintseva Ye.V. – M.: Kolos, 1973. – 272pp. – [in Russian].
28. INTERNATIONAL ATOMIC ENERGY AGENCY, Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments, IAEA -TECDOC-1616. – Vienna: IAEA, 2009.
29. Временные допустимые уровни содержания радионуклидов в объектах контроля Минсельхоза РК, не вошедших в перечень Минздрава Республики, 22.02.94.
Temporary acceptable contents of radionuclides in objects subjected to control by the Ministry of Agriculture RK, which were not included into the list of the Ministry of Public Health RK, 22.02.1994. – [in Russian].
30. Государственные санитарно-эпидемиологические правила и нормативы. Нормы радиационной безопасности (НРБ-99). СП 2.6.1.758-99. Издание официальное. – Алматы, 2000. – 80 с.
State Sanitary-epidemilogical rules and norms. Radiation safety norms regulatory doc (NRB-99). CP2.6.1.758-99. Official Edition.-Almaty, 2000. – 80 pp. – [in Russian].
31. Сельскохозяйственная радиоэкология / под ред. академиков ВАСХНИЛ Р.М. Алексахина и Н.А. Корнеева. – Москва, 1991. – С. 57-58.
Agricultural radioecology //Ed.by Academicians Aleksakhin R.M. and Korneyev N.A. – Moscow, 1991.- pp.57-58. – [in Russian].
32. Постановление Правительства Республики Казахстан "Об утверждении ставок платы за пользование животным миром" от 14 ноября 2008 года № 1061, "Казахстанская правда" от 22 ноября 2008 года № 255 (25702)
Governmental Decree RK "About tariffs for use of animals" from Nov.14, 2008 #1061. – [in Russian].

33. Гигиенические требования к безопасности и пищевой ценности пищевых продуктов: Санитарные правила и нормы №4.01.071.02: утв. Приказом Министра здравоохранения РК от 11.06.2003 г. № 447.
Hygienic requirements to safety and food value of food: Sanitary rules and norms #4.01.071.02: Order of the Minister of Public Health RK from 11.06.2003 #447. – [in Russian].
34. Корнеев П.А. Основы радиоэкологии сельскохозяйственных животных / П.А. Корнеев, А.Н. Сироткин – М.: Энергоатомиздат, 1987.– С. 184.
Kornayev P.A. Fundamentals of radioecology of agricultural animals// Kornayev P.A., Sirotkin A.N. – M.:Energoatomizdat, 1987. – p.184. – [in Russian].
35. Алексахин Р.М. Сельскохозяйственная радиоэкология /под ред. Р.М. Алексахина, Н.А. Корнеева. – М.: Экология, 1992. – 400 с.
Aleksakhin R.M. Agricultural radioecology // Ed.by Aleksakhin R.M., Korneyev N.A. – M.: Ecologiya, 1992. – 400 pp. – [in Russian].
36. Исаков К.И. Пастбища и сенокосы степной зоны / К.И. Исаков. – Алматы: Гылым, 1993. - С.51-62.
Iskakov K.I. Pastures and hayfields of steppe zone // Almaty, Gylym, 1993. pp. 51-62. – [in Russian].
37. Разработка стандартов экологической очистки для защиты будущих поколений: Научная основа сценария "фермер, ведущий натуральное хозяйство", и его применение при расчете допустимого уровня загрязнения почвы радионуклидами для Роки-Флэтс. Арджун Макхиджани и Шрирам Гопал. – 2001, декабрь.
Setting cleanup standards to protect future generations: the scientific basis of the subsistence farmer scenario and its application to the estimation radionuclide soil action levels for Rocky Flats. / By Arjun Makhijani, Ph.D. and Sriram Gopal. – Dec. 2001. http://www.ieer.org/reports/rocky/6rsals.html
38. Минимальные нормы потребления основных продуктов питания для различных социальных групп населения Республики Казахстан.
Minimal consumption rates for basic food products for various social groups of Kazakhstani population. – [in Russian].
39. Гусев Н.Г. Радиоактивные выбросы в биосфере. Справочник, 2-изд. / Н.Г. Гусев, В.А. Беляев – Энергоатомиздат, 1991.
Gusev N.G. Radioactive releases to the biosphere. Reference book, issue 2 // Gusev N.G., Belyaev V.A. – Energoatomizdat, 1991. – [in Russian].

ССП АУМАҒЫ «БАТЫС» БӨЛІГІНІҢ РАДИОЭКОЛОГИЯЛЫҚ АХУАЛЫ

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Мақалада Қарағанды облысының 560 км^2 алаң шегінде орналасқан, Семей сынақ полигоны (ССП) аумағы батыс бөлігінің радиоэкологиялық ахуалының нәтижелері ұсынылған. Қоршаған ортра элементтерінің: құмдақтопырақ, су нысандары, ауа бассейні, өсімдік жамылғысы, жануарлар әлемінің қазіргі радиоэкологиялық ахуалы бағаланды. Зерттеліп жатқан аумақтың топырақтарындағы табиғи радионуклидтердің орташа құрамы Қазақстанның топырақтары үшін үйреншікті болып табылады, қандай да бір геохимиялық ауытқулар анықталған жоқ. ССП аумағы батыс бөлігінің табиғат ортасының нысандарындағы жасанды радионуклидтер құрамы, негізінен, ауқымды радиоактивті түсулерге байланысты. Тұтасымен алғанда, ^{137}Cs және ^{90}Sr радионуклидтерінің алаң бойынша таралуы жеткілікті тегіс. ^{241}Am алаңдық таралуын талдау кезінде тиесілі белсенділіктің жоғары мәндері бар аймақтар анықталды. ^{137}Cs және ^{90}Sr радионуклидтерінің тиесілі белсенділігінің максималды мәндері аумақтың экологиялық жағдайын "салыстырмалы қанағаттанарлық жағдай" ретінде сипаттайтын деңгейлерден төмен. Зерттелген аумақтар $^{239+240}$Pu радионуклидтерінің топырақтағы құрамы бойынша "экологиялық салыстырмалы қанағаттанарлық жағдай" бар аумақтарға жатады. Радионуклидтердің өсімдік жамылғысы, су және ауадағы құрамы, сондай-ақ жануар және өсімдік тектес азық-түлік тағамдарындағы күтілетін құрамы рауалы деңгейлерден көп төмен. Радионуклидтерінің құрамы туралы деректен негізінде табиғат ортасы нысандары мен азық-түлік тағамдарында тұрғындардың дозалық жүктемесіне бағалау жасалды. "Ластанған аумақ шектерінде табиғи шаруашылық жүргізетін фермер" сценарийінің «аса нашар» жағдайы кезінде күтілетін жылдық тиімді доза бір адамға 0,3 мЗв аспайды, бұл Радиациялық қауіпсіздік нормаларына сәйкес араласу деңгейінен төмен болып табылады. Сонымен, жүргізілген кешенді зерттеулер нәтижесінде ҚР нормативтік базасының қолданыстағы талаптарын ескере отырып, барлық зерттелген аумақты шектеусіз пайдалануға болады.

Аталған зерттеулер жерлерді ары қарай шаруашылық айналымға беру мақсатында жүргізілді.

Түйін сөздер: ядролық сынақтар, радиоэкология, радиоактивтік ластану, радионуклидтер, өсімдік жамылғысы, супайдалану нысандары, тәртіп сценарийі, дозалық жүктемелер.

РАДИОЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ «ЗАПАДНОЙ» ЧАСТИ ТЕРРИТОРИИ СИП

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В статье представлены результаты радиоэкологических исследований западной части территории Семипалатинского испытательного полигона (СИП), расположенной в пределах Карагандинской области на площади 560 км^2. Оценено современное радиоэкологическое состояние элементов окружающей среды: почвогрунтов, водных объектов, воздушного бассейна, растительного покрова, животного мира. Среднее содержание естественных радионуклидов в почвах исследуемой территории является типичным для почв Казахстана, каких-либо геохимических аномалий не выявлено.Содержание искусственных радионуклидов в объектах природной среды западной части территории СИП обусловлено, в основном, глобальными радиоактивными выпадениями. В целом, распределение радионуклидов ^{137}Cs и ^{90}Sr по площади достаточно равномерное. При анализе площадного распределения ^{241}Am выявлены зоны с повышенными значениями удельной активности. Максимальные значения удельной активности радионуклидов ^{137}Cs и ^{90}Sr ниже уровней, характеризующих экологическое состояние территорий как "относительно удовлетворительная ситуация". Обследованные территории по содержанию в почвах радионуклидов $^{239+240}$Pu относятся к территориям с "относительно удовлетворительной экологической ситуацией". Содержание радионуклидов в растительном покрове, воде и воздухе, а также ожидаемое содержание в продуктах питания животного и растительного происхождения значительно ниже допустимых уровней. 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 на человека не превысит 0,3 мЗв, что является ниже уровня вмешательства, согласно Нормам радиационной безопасности. Таким образом, по результатам проведенного комплексного обследования, с учетом существующих требований 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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RADIONUCLIDE CONTAMINATION OF SHAGAN RIVER (2010 RESULT)

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The study of contamination with radionuclides continued in 2010 at Shagan river bed and its tributary Ashchisu. We examined the bed from the southern to the northern boundary of the STS. Data were obtained on the content of artificial radionuclides, salinity of waters in the river. Specific activity of ^{3}H in the bed waters in the area with the highest concentrations is for an order of magnitude lower than the values recorded in 2009. The numerical values for ^{3}H specific activity in the surface waters are recorded throughout the Shagan River to its confluence with Irtysh River. Specific activity of ^{3}H in Shagan River and its tributary Ashchisu down to "Atomic" Lake is below the detection limits. Specific activities of ^{137}Cs, $^{239+240}$Pu throughout the studied Shagan river bed are below the detection limit of the instrumentation used.

Ashchisu River shows high salinity and belongs to salty waters. The values of salinity are stable throughout the investigated bed.

Keywords: tritium, radionuclide contamination, Atomic Lake, specific activity, salinity, groundwater, bed water.

INTRODUCTION

The main pathway for tritium contamination in the bed of Shagan River is its migration with groundwater. The main area of groundwater discharge is between 4 km and 5 km from "Atomic" Lake, which is characterized by maximal specific activities of tritium. All the investigated beds are characterized by sharp fluctuations of both salinity indicators, as well as specific activity of tritium. The increase in specific activity of tritium after the minimal one evidences about migration of tritium with groundwater, flowing to the surface over the bed. Based on the specific activity of tritium and salinity one can state that there are several of these areas over the bed. The radionuclides ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am and ^{152}Eu get to the river bed waters most likely as result of washing-out of coastal soils and sediments.

At the moment there is a considerable amount of research data on Shagan River waters on the section from "Atomic" Lake up to 12 km. Before "Atomic" Lake, Shagan River and its tributary Aschisu hardly been studied for radionuclide and chemical composition. Also there is insufficient data on the composition of Shagan River waters over the bed to the confluence with Irtysh River.

The purpose of this paper is to study the bed waters of Shagan River from "Atomic" Lake to the confluence with Irtysh River, and determination of radionuclide contamination throughout the bed, both before and after "Atomic" Lake. To study situation changes over time it is necessary to monitor the tritium content in the area of its maximum.

1. EXPERIMENT

All studies were carried out during the year 2010. The field studies included visual inspection of the facilities; assessment of flow rates at selected points; water sampling for laboratory studies. The laboratory testing of water samples included determination of artificial radionuclides – ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, ^{241}Am and ^{152}Eu; determination of total salinity.

1.1. Sampling procedure

1.1.1. Shagan River and Aschisu River up to "Atomic" Lake

Aschisu and Shagan rivers up to "Atomic" Lake were sampled on sections of the bed from the STS boundary up to "Atomic" Lake. Distance between the sampling points was about 2 km, but in some areas the sampling points were displaced along the river from the planned ones due to insufficient amount of water in the bed. The sampling points along Shagan river bed and Aschisu river bed up to "Atomic" Lake are shown in Figure 1.

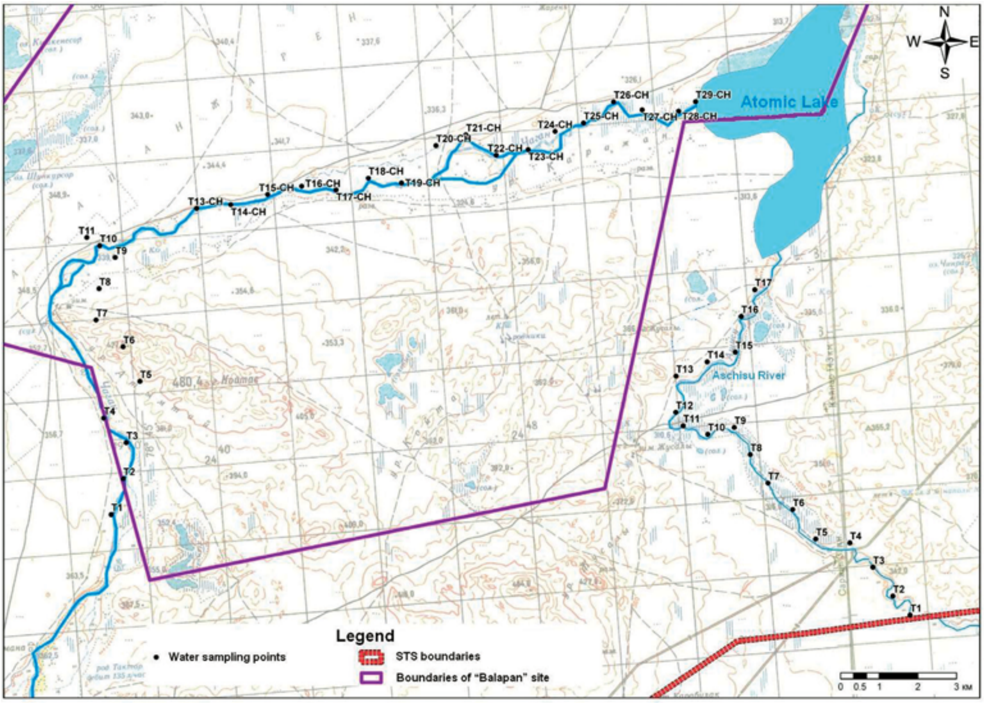

Figure 1. Sampling points along Shagan river bed and Aschisu river bed up to "Atomic" Lake

1.1.2 Shagan River after "Atomic" Lake

The sampling points on the Shagan river bed area after "Atomic" Lake were selected based on survey data from previous years. Up to 12 km from "Atomic" Lake, in areas with the highest tritium contamination the spacing between the sampling points ranged from 100 m to 200 m. Between the STS boundary and Irtysh River the samples along the riverbed were taken at intervals from 1 km to 5 km. Water sampling points along the Shagan river bed after flowing from "Atomic" Lake are shown in Figure 2.

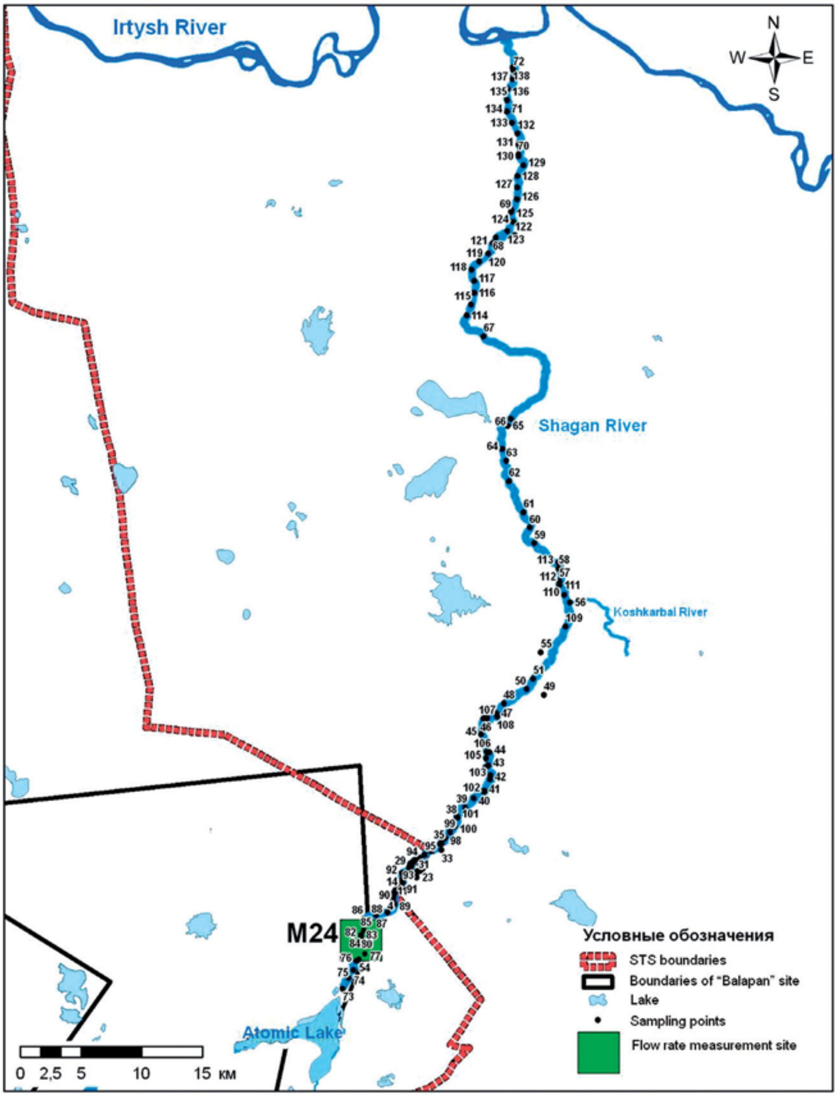

Figure 2. Water sampling points along the Shagan river bed after flowing out from "Atomic" Lake

1.2. Sampling

Sampling was carried out during the entire field season from April to November. All samples were placed into sealed plastic containers.

Sampling to determine specific activity of tritium

The samples for tritium determination were taken in volume of 0.2 litres, according to the ST RK GOST R 51592-2003 "Water. Basic requirements for sampling ".

Sampling to determine specific activity of the radionuclides ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, ^{241}Am and ^{152}Eu

The samples to determine ^{90}Sr, ^{137}Cs, $^{239+240}$Pu were taken in volume of 10 litres. The samples to determine ^{241}Am and ^{152}Eu were taken in volume of 100 litres. The samples to determine ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am and ^{152}Eu were filtered immediately after sampling and preserved by nitric acid (high purity) at a rate of 3 ml per 1 litre of sample.

Sampling to determine total salinity

To determine the total salinity the water samples were taken at 1-liter volume, in accordance with the ST RK GOST R 51592-2003 "Water. Basic requirements for sampling".

Immediately after sampling the samples were transported to the laboratory for further research.

1.3. Determination of radionuclide composition

Determination of tritium

^{3}H was determined by liquid scintillation spectrometry at β-spectrometer TriCarb-2900 TR according to ISO 9698/1989 [2].

Determination of ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, ^{241}Am and ^{152}Eu

^{90}Sr, ^{137}Cs, $^{239+240}$Pu were determined by spectrometric methods after radiochemical separation [3] from the pre-concentrated precipitation of salts – co-precipitants with radionuclides. ^{90}Sr was precipitated with calcium carbonate, ^{137}Cs - with copper hexacyanoferrates, $^{239+240}$Pu - with iron hydroxide (III) [4]. ^{241}Am and ^{152}Eu were determined after pre-concentration with hydroxide to iron (III) according to the developed internal methodology for concentration. Specific activities of ^{137}Cs, ^{241}Am and ^{152}Eu were measured on γ-spectrometer ORTEC GMX 20P4. Specific activity of ^{90}Sr was measured in accordance with the method [5] using beta-spectrometer TriCarb-2900 TR. Alpha-spectrometric measurements of $^{239+240}$Pu specific activities were performed on a spectrometer Canberra.

1.4. Determination of total salinity

The total salinity was determined by gravimetric method according to GOST 26449.1-85 "Methods for Chemical Analysis of salt water". The method consists of evaporation and annealing of the water samples to dryness followed by determination of its mass.

1.5. Determination of watercourse flow rate

To measure the water flow at section 4.7 km from "Atomic Lake" the riverbed was partitioned off with special boxes so that water flowed only over the box. We measured the depth of flow at the beginning and end of the box - H_1 and H_2 (in meters), and calculated the mean value. We had a float to run through the box and timed its passage t(c). This procedure was repeated several (3-5) times. The average flow velocity (m/s) was calculated by the formula $V_{av} = L/t_{av}$, where L - length of the box (m). The watercourse flow rate (m^3/s) was calculated by the formula $Q = S_{av} * V_{av}$.

2. RESULTS

2.1. Studies of Aschisu River waters up to "Atomic Lake"

2.1.1. Radionuclide composition

Study results of the radionuclide composition in Aschisu River waters are presented in Table 1.

Table 1.

Specific activity of radionuclides in Aschisu River waters

##	Sampling place	Sampling point	^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
1	Aschisu River	T1	<8	<0.01	0.027±0.007	<0.0007
2	Aschisu River	T2	<8	<0.02	0.15±0.01	-
3	Aschisu River	T3	<7	-	-	-
4	Aschisu River	T4	<7	-	-	-
5	Aschisu River	T5	<8	<0.01	0.049±0.008	<0.0008
6	Aschisu River	T6	<8	-	-	-
7	Aschisu River	T7	<7	<0.01	0.103±0.006	-
8	Aschisu River	T8	<8	-	-	-
9	Aschisu River	T9	<7	<0.01	0.054±0.005	-
10	Aschisu River	T10	<7	-	-	-
11	Aschisu River	T11	<8	<0.01	0.041±0.005	-
12	Aschisu River	T12	<7	-	-	-
13	Aschisu River	T13	<7	<0.01	0.039±0.006	<0.0007
14	Aschisu River	T14	<7	-	-	-
15	Aschisu River	T15	<7	<0.01	0.065±0.006	-
16	Aschisu River	T16	<7	-	-	-
17	Aschisu River	T17	<7	<0.01	0.021±0.005	<0.0007

Salinity

Mean values of total salinity for Aschisu River waters are shown in Table 2.

Table 2.

Total salinity of Aschisu River waters

##	Sampling point	Salinity mg/dm³	#	Sampling point	Salinity mg/dm³	##	Sampling point	Salinity mg/dm³
1	T1-A	22480±200	7	T7-A	22000±200	13	T13-A	22480±200
2	T2-A	22440±200	8	T8-A	21720±200	14	T14-A	22520±200
3	T3-A	22440±200	9	T9-A	21720±200	15	T15-A	22400±200
4	T4-A	22240±200	10	T10-A	21400±200	16	T16-A	22280±200
5	T5-A	22200±200	11	T11-A	21840±200	17	T17-A	19760±200
6	T6-A	22040±200	12	T12-A	23560±200			

2.2. Studies of Shagan River waters up to "Atomic Lake"

2.2.1. Radionuclide composition

Study results of the radionuclide composition in Shagan River waters up to "Atomic Lake" are presented in Table 3.

Table 3.

Specific activity of radionuclides in Shagan River waters up to "Atomic Lake"

##	Sampling place	Sampling point	^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}Pu$, Bq/kg
1	Shagan River	T1	<7	-	-	-
2	Shagan River	T2	<7	-	-	-
3	Shagan River	T3	<7	<0.01	<0.0083	<0.00067
4	Shagan River	T4	<8	-	-	-
5	Shagan River	T5	<7	<0.01	<0.0084	-
6	Shagan River	T6	<7	-	-	-
7	Shagan River	T7	<8	<0.02	0.01±0.005	<0.00076
8	Shagan River	T8	<8	-	-	-
9	Shagan River	T9	<7	<0.01	<0.008	-
10	Shagan River	T10	<8	-	-	-
11	Shagan River	T11	<8	<0.01	<0.008	
12	Shagan River	T13	<8	<0.01	<0.008	<0.00058
13	Shagan River	T14	<8	-	-	-
14	Shagan River	T15	<7	<0.01	<0.008	-
15	Shagan River	T16	<7	-	-	-
16	Shagan River	T17	<7	<0.01	0.018±0.003	<0.00067
17	Shagan River	T18	<8	-	-	-
18	Shagan River	T22	<8	-	-	-
19	Shagan River	T23	<8	<0.01	<0.0055	-
20	Shagan River	T24	<9	-	-	-
21	Shagan River	T25	<8	-	-	-
22	Shagan River	T26	<8	-	-	-
23	Shagan River	T27	<8	-	-	-

2.2.2. Salinity

Total salinity values are given in Table 4.

Table 4.

Total salinity of Shagan River waters before confluence with "Atomic Lake"

#	Sampling point	Salinity, mg/dm³	#	Sampling point	Salinity, mg/dm³	#	Sampling point	Salinity, mg/dm³
1	T1-CH	2600±20	6	T6-CH	3880±40	11	T11-CH	2200±20
2	T2-CH	2400±20	7	T7-CH	3560±30	12	T13-CH	2760±20
3	T3-CH	2180±20	8	T8-CH	3580±30	13	T14-CH	4620±40
4	T4-CH	3120±30	9	T9-CH	3420±30	14	T15-CH	5629±50
5	T5-CH	3260±30	10	T10-CH	3480±30	15	T16-CH	5020±50

2.3. Study of Shagan River waters after flowing out from "Atomic Lake"

2.3.1. Flow rate

The bed water flow rate compared to previous years has increased by an order of magnitude. The mean value of the flow rate in 2009 was 130 l/min, in 2010 – 1,500 l/min. In this connection, an increase should be expected in radionuclides proliferation rate along the river against the general decline in the specific activity of radionuclides due to dilution.

2.3.2. Radionuclide composition

Figure 3 shows distribution of tritium specific activity in the waters of Shagan River along the channel from "Atomic Lake" up to confluence with Irtysh River (there was no water in the river bed between 53rd and 82nd km from "Atomic Lake").

Maximal concentrations of tritium specific activity are recorded at section 4.7 km and are 54 kBq/kg. Specific activity of tritium changes abruptly. Of particular interest is the fact that the numerical values of tritium specific activity in surface waters are recorded throughout Shagan River up to the confluence with Irtysh River.

According to our studies, the levels of tritium specific activity are significantly different from the levels recorded in previous years.

In general, tritium specific activity in the water of the area with the highest values is for an order of magnitude lower than that in 2009. This is probably due to the large influx of meltwater. The flow rate of the bed water has increased by an order compared to previous years. The meltwater inflow into the bed caused significant dilution and this resulted in recording of lower tritium specific activity in comparison with the past studies.

Starting from 20 km down "Atomic Lake" there is a trend to a decrease in tritium specific activity in the waters of the bed, and from 80 km down "Atomic Lake" to the confluence of Shagan River with Irtysh River tritium specific activity is 200 Bq/kg in average.

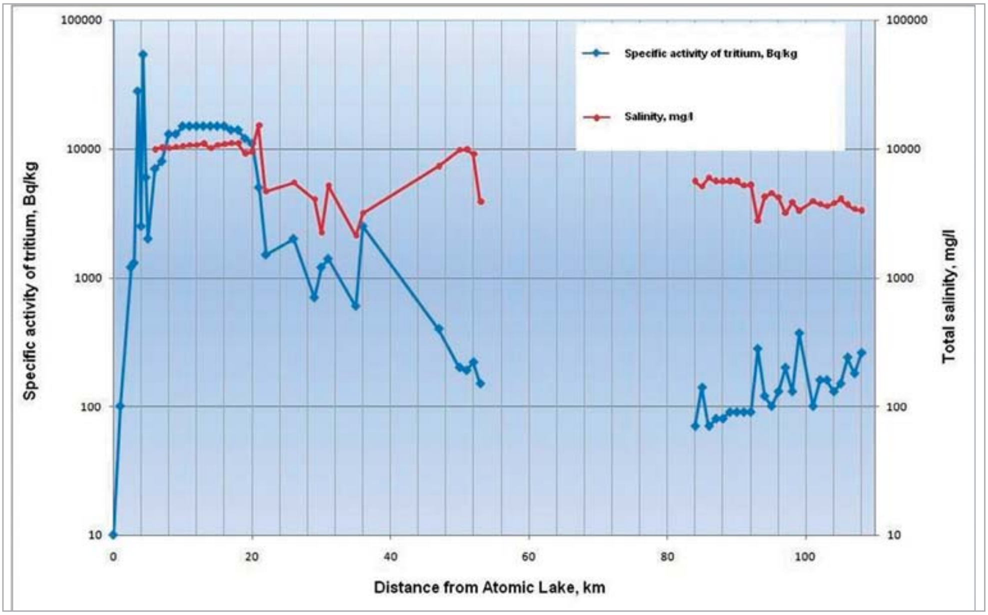

Figure 3. Distribution of tritium specific activity and total salinity in the waters of Shagan River

In 2010 specific activity of tritium was monitored in the area of its maximum (Figure 4).

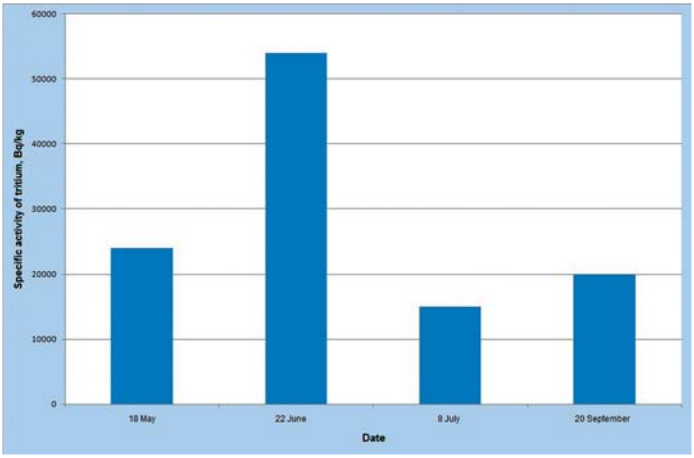

Figure 4. Tritium specific activity at its maximum (4.7 km from "Atomic Lake")

The monitoring found that ^{3}H specific activity throughout the study period is for an order lower than that last year. At that, the content of ^{3}H at one point during the year can vary quite significantly from 15 kBq/kg to 54 kBq/kg. It was also found that the concentration of

^{3}H is in direct relation with the watercourse flow rate. The higher flow rate is, the smaller ^{3}H activity is. It should also be noted that distribution of ^{3}H in the river bed depends on the flow rate of the watercourse, i.e. in the flood period the determined concentration of ^{3}H can be observed at very large distances from the point of maximum, up to the confluence with Irtysh River.

According to the studies, specific activities of ^{137}Cs, $^{239+240}Pu$ are below the detection limits of the methods used. ^{90}Sr was detected in several water samples taken up to 6 km from "Atomic Lake", that is due to wash-out of radionuclides from the sediments (Annex 1).

2.3.3. Salinity

Total salinity in Shagan River waters after flowing out from "Atomic Lake" is given in Table 5 and Figure 3.

Table 5.

Total salinity in Shagan River waters after flowing out from "Atomic Lake"

#	Sampling point	Salinity, mg/dm³	#	Sampling point	Salinity, mg/dm³	#	Sampling point	Salinity, mg/dm³
1	T-6km	9880±100	19	T-28km	3840±30	37	T-91km	5200±50
2	T-7km	10200±100	20	T-29km	4040±40	38	T-92km	5240±50
3	T-8km	10120±100	21	T-30km	2220±20	39	T-93km	2760±30
4	T-9km	10280±100	22	T-31km	5160±50	40	T-94km	4240±40
5	T-10km	10440±100	23	T-35km	2120±20	41	T-95km	4480±40
6	T-11km	10720±100	24	T-36km	3160±30	42	T-96km	4200±40
7	T-12km	10640±100	25	T-47km	7320±70	43	T-97km	3160±30
8	T-13km	10960±100	26	T-50km	9720±100	44	T-98km	3852±40
9	T-14km	10160±100	27	T-51km	9840±100	45	T-99km	3320±30
10	T-15km	10640±100	28	T-52km	9120±90	46	T-100km	1620±15
11	T-16km	10800±100	29	T-53km	3880±40	47	T-101km	3920±40
12	T-17km	11000±100	30	T-84km	5600±60	48	T-102km	3720±40
13	T-18km	11040±100	31	T-85km	5120±50	49	T-103km	3600±40
14	T-19km	9200±90	32	T-86km	5960±60	50	T-104km	3760±40
15	T-20km	9400±90	33	T-87km	5600±60	51	T-105km	4080±40
16	T-21km	15120±150	34	T-88km	5600±60	52	T-106km	3680±40
17	T-22km	4680±40	35	T-89km	5600±60	53	T-107km	3400±30
18	T-26km	5440±50	36	T-90km	5480±50	54	T-108km	3320±30

Concentrations of ^{137}Cs, $^{239+240}Pu$ in the bed waters are below the detection limits. The content of ^{90}Sr varies from 0.03-0.15 Bq/kg.

Waters of Aschisu River have a high salt content and refer to the salty waters. Salinity throughout the investigated area varies slightly.

Concentrations of ^{3}H, ^{137}Cs, $^{239+240}Pu$ in the bed waters of Shagan River up to the confluence with "Atomic Lake" are below the detection limits of the measuring equipment.

The content of ^{90}Sr in the majority of points is also below the detection limit, but numerical values were obtained in two samples of water about 0.01 Bq/kg.

The total salinity says that the high salt content comes to Shagan River with the waters of Aschisu River.

DISCUSSION OF RESULTS

The investigations in 2010 revealed that ^{3}H specific activity in the waters of Shagan River and its tributary Aschisu to "Atomic Lake" is below the detection limits of the instrumentation used, which indicates that the tritium contamination enters Shagan River bed after flowing from "Atomic Lake". ^{3}H specific activity in bed waters in the areas with the highest concentrations is for an order of magnitude lower than the concentrations measured in 2009. This is probably due to the large dilution of meltwater in spring - summer period in 2010. The numerical values of ^{3}H specific activity in surface waters are recorded throughout Shagan River up to confluence with Irtysh River. Starting from 80 km and down from "Atomic Lake" to the confluence of Shagan River with Irtysh River specific activity of ^{3}H is 200 Bq/kg in average. After the 80km, there is a slight increase in the specific activity of tritium in the waters of the river starting from 80th km and downstream, which is not typical at proliferation with surface waters from the source of contamination located upstream.

The specific activity of ^{90}Sr in the waters of Shagan River and Aschisu River before falling in "Atomic Lake" is in the range 0.01-0.03 Bq/kg. The specific activities of ^{137}Cs, $^{239+240}Pu$ throughout the studied bed of Shagan River are below the detection limits of measuring equipment. High salinity of Shagan River is caused by large amounts of soluble salts which come with the waters of the right tributary of Aschisu River, as the salinity of Aschisu River is several times higher than the salinity of Shagan River.

The salinity level throughout the bed of Aschisu River changes slightly, the salinity of Shagan River after "Atomic Lake" changes in a wide range.

CONCLUSION

Tritium contamination gets into Shagan River after "Atomic Lake". Since 80 km after "Atomic Lake", the specific activity of tritium in the water increases, there is another inflow of groundwater contaminated with tritium. In this case the hazard of tritium contamination in Irtysh River is much higher than it was previously thought.

Waters of Shagan and Aschisu have ^{90}Sr, this is due to wash-out of radionuclides from the sediment. In the future, dynamics of strontium contamination levels needs to be studied in the waters of Aschisu and Shagan rivers. No radionuclides ^{137}Cs, $^{239+240}Pu$ in the waters Shagan and Aschisu rivers were detected due to high dilution of the bed waters with melt waters and related decrease in the specific activity of radionuclides as compared with the previous years.

The entire set of currently available data allows us to draw up an overall picture of Shagan River salinity and its tributary Aschisu. In general, the situation is characterized by the following features: the overall salinity of Aschisu River is several times higher than that in Shagan River; salinity of Aschisu River is stable throughout the investigated bed, no abrupt changes in salinity over the bed are observed, which indicates the absence of groundwater inflows, salinity level of Shagan River up to "Atomic Lake" changes slightly, but after flowing from "Atomic Lake" there are sharp fluctuations in the salinity levels, which indicates the presence of areas with water exchange with ground waters throughout the bed.

In order to predict the spread of radionuclide contamination in the waters of Shagan River, further research is needed, in particular, continuous monitoring of the channel, underflow and groundwater, determination of the exact direction of the tritium contamination proliferation with groundwater.

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REFERENCES

1. Safety Assurance of the former Semipalatinsk test site. Republican Budgetary Program 011 "Radiation Safety: A Report on R&D (information report) / A.V. Drozdov - Almaty: IGR NNC RK, 2009. [in Russian]
   Обеспечение безопасности бывшего семипалатинского испытательного полигона. Республиканская бюджетная программа 011 "Обеспечение радиационной безопасности: отчет о НИР (информационный отчет) / рук. Дроздов А.В. – Алматы: ИГИ НЯЦ РК, 2009.
2. ISO 9698:1989 (E). Water quality - Determination of tritium activity concentration – Liquid scintillation counting method.
3. The method for determination of artificial radionuclides $^{239+240}Pu$, ^{90}Sr in the environment. KZ/07/00/00471-2005 /. [in Russian]
   Методика определения содержания искусственных радионуклидов $^{239+240}Pu$, ^{90}Sr в объектах окружающей среды. KZ/07/00/00471-2005/.
4. The method for determining the content of artificial radionuclides of plutonium (239+240), strontium-90 and cesium-137 in natural waters by concentration. - Almaty, 2001. [in Russian]
   Методика определения содержания искусственных радионуклидов плутония-(239+240), стронция-90 и цезия-137 в природных водах методом концентрирования. - Алматы, 2001.
5. The method for determination of artificial radionuclides $^{239+240}Pu$, ^{90}Sr in the environment, KZ/07/00/00471-2005 /. [in Russian]
   Методика определения содержания искусственных радионуклидов $^{239+240}Pu$, ^{90}Sr в объектах окружающей среды, KZ/07/00/00471-2005/

ШАҒАН ӨЗ. СУЛАРЫНЫҢ РАДИОНУКЛИДТІ ЛАСТАНУ ДЕҢГЕЙІ МЕН СИПАТЫН ЗЕРТТЕУ (2010 ЖЫЛДЫҢ НӘТИЖЕЛЕРІ)

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2010 жылы Шаған өз. мен оның құйылысы болатын Ащысу өз. арнасына зерттеу жалғастырылды. ССП оңтүстік шекарасынан солтүстік шекарасына дейінгі арнасы зерттелді. Өзен суларындағы техногенді радионуклидтердің, судың минералдануының құрамы бойынша деректер алынды. Максималды мәндері бар телімдердегі арна суларында ^{3}H тиесілі белсенділігі 2009 жылдың мәндерінен бір ретке төмен. Беткі сулардағы ^{3}H тиесілі белсенділігінің сандық мәндері Шаған өз. бойымен Ертіс өз. дейін тіркеледі. Шаған өз. мен оның құйылысы Ащысу өз. арна суларындағы ^{3}H тиесілі белсенділігі «Атом көліне» дейін табу шегінен төмен жатыр. 137Cs, 239+240Pu Шаған өз. зерттелген арнасының бүкіл бойымен қолданылатын әдістердің табу шектерінен төмен.

Ащысу өз. суларының құрамы жоғары тұзды және тұзды суларға жатады. Минералдану мәндері зерттелген арна бойымен тұрақты.

Түйін сөздер: тритий, радионуклидті ластану, Атом көлі, тиесілі белсенділік, минералдану, топырақасты сулар, арнаасты сулар.

ИССЛЕДОВАНИЯ ХАРАКТЕРА И УРОВНЕЙ РАДИОНУКЛИДНОГО ЗАГРЯЗНЕНИЯ ВОД Р. ШАГАН (РЕЗУЛЬТАТЫ 2010 ГОДА)

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В 2010 году было продолжено исследование русла р. Шаган и его притока р. Ашису. Обследовано русло от южной до северной границы СИП. Получены данные по содержанию в водах реки техногенных радионуклидов, минерализации вод. Удельная активность 3Н в русловых водах на участке с максимальными значениями, на порядок ниже значений 2009года. Численные значения удельной активности 3Н в поверхностных водах фиксируются на всем протяжении р. Шаган до впадения в р. Иртыш. Удельная активность 3Н в водах р. Шаган и её притока р. Ашису до «Атомного озера» находится ниже пределов обнаружения. Удельная активность 137Cs, 239+240Pu на всем протяжении исследованного русла р. Шаган находится ниже пределов обнаружения применяемых методов.

Воды р. Ашису имеют высокое солесодержание и относятся к соленым водам. Значения минерализации стабильны на всем протяжении исследованного русла.

Ключевые слова: тритий, радионуклидное загрязнение, Атомное озеро, удельная активность, минерализация, грунтовые воды, русловые воды.

Annex 1.

Specific activities of radionuclides in Shagan River waters

##	Sampling place	Sampling point	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg	^{241}Am, Bq/kg	^{152}Eu, Bq/kg
1	Shagan River	AL dam	<0.01	<0.01	-	-	-
2	Shagan River	AL	<0.01	<0.01	-	<0.01	<0.01
3	Shagan River	1650m	<0.01	0.1±0.01	-	-	-
4	Shagan River	2590m	<0.02	0.12±0.01	-	-	-
5	Shagan River	2770m	<0.03	0.06±0.01	-	-	-
6	Shagan River	3180m	<0.02	0.07±0.01	-	<0.01	<0.01
7	Shagan River	23/7м	<0.01	0.21±0.01	<0.001	-	-
8	Shagan River	5810m	<0.01	0.11±0.01	-	<0.01	<0.01
9	Shagan River	M1	<0.01	<0.01	-	-	-
10	Shagan River	M1/2	<0.01	<0.01	-	-	-
11	Shagan River	M1/3	<0.01	<0.01	-	-	-
12	Shagan River	M22	<0.01	<0.01	-	-	-
13	Shagan River	M23/2	<0.02	<0.01	<0.004	-	-
14	Shagan River	M24/7	<0.01	<0.01	-	-	-
15	Shagan River	M24	<0.03	<0.01	-	-	-
16	Shagan River	M26/1	<0.02	<0.01	-	-	-
17	Shagan River	M27/6	<0.01	<0.01	-	-	-
18	Shagan River	M29/5	<0.01	<0.01	<0.006	-	-
19	Shagan River	M31/1	<0.01	<0.01	-	-	-
20	Shagan River	M32	<0.02	<0.01	-	-	-
21	Shagan River	M33/3	<0.02	<0.01	-	-	-
22	Shagan River	M34	<0.03	<0.01	<0.0025	-	-
23	Shagan River	M35	<0.01	<0.01	-	-	-
24	Shagan River	M36	<0.01	<0.01	-	-	-
25	Shagan River	M37/9	<0.01	<0.01	-	-	-
26	Shagan River	M39/5	<0.01	<0.01	-	-	-
27	Shagan River	M41/1	<0.02	<0.01	-	-	-
28	Shagan River	M43	<0.1	<0.01	-	-	-
29	Shagan River	M47	<0.1	<0.01	-	-	-
30	Shagan River	M78/9	<0.1	<0.01	-	<0.01	<0.01
31	Shagan River	M78/37	<0.1	<0.01	-	-	-
32	Shagan River	8km	<0.03	<0.01	<0.002	-	-
33	Shagan River	9km	<0.04	<0.01	<0.007	<0.01	<0.01

##	Sampling place	Sampling point	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg	^{241}Am, Bq/kg	^{152}Eu, Bq/kg
34	Shagan River	10km	<0.01	<0.01	<0.0018	-	-
35	Shagan River	11km	<0.04	<0.01	<0.00144	-	-
36	Shagan River	12km	<0.01	<0.01	<0.00125	<0.01	<0.01
37	Shagan River	13km	<0.02	<0.01	<0.00108	-	-
38	Shagan River	14,5km	<0.04	<0.01	<0.0014	-	-
39	Shagan River	15km	<0.01	<0.01	<0.00205	-	-
40	Shagan River	16km	<0.01	<0.01	-	-	-
41	Shagan River	17km	<0.01	<0.01	<0.00184	-	-
42	Shagan River	18km	<0.03	<0.01	-	-	-
43	Shagan River	19km	<0.03	<0.01	-	-	-
44	Shagan River	20km	<0.04	<0.01	<0.00184	-	-
45	Shagan River	21km	<0.01	<0.01	<0.00204	-	-
46	Shagan River	22km	<0.01	<0.01	<0.00487	-	-
47	Shagan River	23km	<0.01	<0.01	<0.00447	-	-
48	Shagan River	24km	<0.01	<0.01	<0.0046	-	-
49	Shagan River	25km	<0.02	<0.01	<0.0048	-	-
50	Shagan River	26km	<0.01	<0.02	<0.0064	-	-
51	Shagan River	27km	<0.01	<0.01	<0.013	-	-
52	Shagan River	28km	<0.02	<0.01	<0.0007	-	-
53	Shagan River	29km	<0.01	<0.01	<0.0028	-	-
54	Shagan River	30km	<0.01	<0.01	<0.003	-	-
55	Shagan River	35 km	<0.02	<0.02	<0.00068	-	-
56	Shagan River	50 km	<0.01	<0.01	-	-	-
57	Shagan River	55 km	<0.02	<0.01	<0.00062	-	-
58	Shagan River	60 km	<0.01	<0.01	-	-	-
59	Shagan River	65 km	<0.03	-	<0.00065	-	-
60	Shagan River	70 km	<0.01	-	-	-	-
61	Shagan River	75 km	<0.01	-	<0.00067	-	-
62	Shagan River	80 km	<0.01	<0.0077	-	-	-
63	Shagan River	90 km	<0.01	-	<0.00056	-	-
64	Shagan River	95 km	<0.01	-	-	-	-
65	Shagan River	100 km	<0.02	-	-	-	-
66	Shagan River	110 km	<0.01	<0.01	-	-	-

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MECHANISMS FOR SURFACE CONTAMINATION OF SOILS AND BOTTOM SEDIMENTS IN SHAGAN RIVER ZONE

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Shagan River is the only surface watercourse within the former Semipalatinsk Test Site (STS). Relevant researches in the Shagan River valley were carried out to study possible migration of artificial radionuclides with surface waters over considerable distances, and thus proliferation into Irtysh River. The investigations revealed that the radioactive contamination of soil was primarily caused by the first underground nuclear test with soil outburst, conducted at "Balapan" site in the well 1004. The ground nuclear tests carried out at "Experimental Field" site and global fallouts made insignificant contribution to the contamination. The most polluted is the area in the immediate vicinity of the "Atomic" Lake crater. Contamination at the site is of areal nature. The total area of contamination is limited to 10 – 12 km from the crest of the crater. It was revealed that a good identification parameter to determine the source of soil contamination is the ratio of plutonium isotopes. The laboratory analyses of bottom sediments allowed revealing and adjusting the position of the traces from nuclear weapons testing at "Experimental field" site. The works revealed the virtual absence of artificial radionuclides migration with surface waters, and fears of a possible cross-border transfer of radionuclides with the waters of Shagan and Irtysh rivers were not confirmed.

Keywords: nuclear testing, "Atomic" Lake, surface contamination, radionuclides, formation mechanisms, migration.

1. INTRODUCTION

Shagan River is the only surface watercourse within the former Semipalatinsk Test Site (STS). It flows along the eastern boundary of the STS and is the left-bank tributary of Irtysh River. The nuclear tests at STS caused to some extent radioactive contamination in Shagan River Valley. Herewith there is a hazard of potential radionuclide transport with waters of Shagan River and radioactive contamination of Irtysh River.

The following factors might affect the formation of radionuclide contamination in the valley of Shagan River: global atmospheric precipitations, atmospheric fallouts from nuclear explosions at "Experimental field" site, atmospheric fallouts and outburst of contaminated rock caused by the excavational explosion in the well 1004, wind-driven transfer and proliferation of radionuclides with surface waters from the zone of soil heaps around "Atomic" Lake, inflow of groundwater contaminated with radionuclides from the area of the "warfare" wells.

The most significant contamination of the area was caused by the underground nuclear explosion with outburst of soil "Chagan" in the well 1004 conducted in 1965 at the confluence of Shagan and Aschisu rivers. It was the first experimental-industrial test with a goal to obtain information about the possibilities for using nuclear charges to build water reservoirs in arid regions of the former Soviet Union, particularly in Kazakhstan. In the soil piles zone, the explosion caused fallout of 30-40 % of radionuclides from their total generated amount.

The following long-lived radionuclides were generated: $^{239,240}Pu$ – 8,5 Ci; ^{137}Cs – 800 Ci; ^{60}Co – 80 Ci; ^{152}Eu – 120 Ci; ^{90}Sr – 400 Ci; ^{3}H – $4 \cdot 10^{5}$ Ci [1].

The previous studies found that the maximal content of radionuclides in the soil is observed within the ground heap area, beyond which they are reduced to the background levels [2]. The concentrations of artificial radionuclides in bottom sediments and coastal soils are maximal near "Atomic" Lake and decrease at larger distances; and at distances greater than 10 km the concentrations are comparable to those typical for background of global fallouts [3]. A typical feature of this contamination is the presence of activation products in the bottom sediment: ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{60}Co at considerable distances – up to 12 km away from "Atomic" Lake. In addition, in some areas of Shagan River, the most accessible for water use, it was possible to detect the isotopes ^{152}Eu and ^{241}Am in the water. Specific activity of ^{241}Am in average was $2 \cdot 10^{-3}$ Bq/kg. Specific activity of ^{152}Eu was not more than $3 \cdot 10^{-4}$ Bq/kg. Presence of these radionuclides in water at distances of up to 6 km from the alleged contamination source is of concern since Shagan River is a tributary of one of the largest rivers in Kazakhstan – Irtysh River, and in this case, there is a hazard of cross-border migration of radionuclides with surface waters.

Presence of multiple sources, non-uniformity of spatial contamination distribution from each source creates a very complex mechanism for formation of radioactive contamination of soils in the Shagan River valley. In this connection, the main goal of this research is to study the mechanisms of contamination and possible proliferation of artificial radionuclides from the soil heap zones of "Atomic" Lake with the surface waters of Shagan River.

2. EXPERIMENT

For our purposes we measured levels of artificial radionuclides in bottom and coastal sediments and soils of Shagan River valley. The contribution to the contamination of Shagan River soils from atmospheric nuclear tests was assessed by determination of the radionuclides concentration in the profiles perpendicularly crossing the projected axis of the traces from the explosion carried out at the "Experimental field" site.

2.1. Soil sampling

The field works included: gridding the soil sampling points and surface sampling of soils and bottom sediments.Arrangement of sampling points is shown in the figure (Figure 1).

The sampling points were gridded using a satellite global positioning unit (GPS-receiver), which allows determining the position of points in the geographic coordinate system WGS-84. The survey points were positioned in geodetic coordinate system, where: B – geodetic latitude, L – geodetic longitude (in degrees, minutes and seconds). The accuracy of determining the coordinates by GPS-receiver is 3-5 meters with a probability of 95%.

The sampling was carried out using a special sampler. The area of the spot sampling was 100 cm^2, the depth was 5 cm. The samples were collected and packaged in compliance with the requirements for soil sampling in conditions of areal and local contaminations [4].

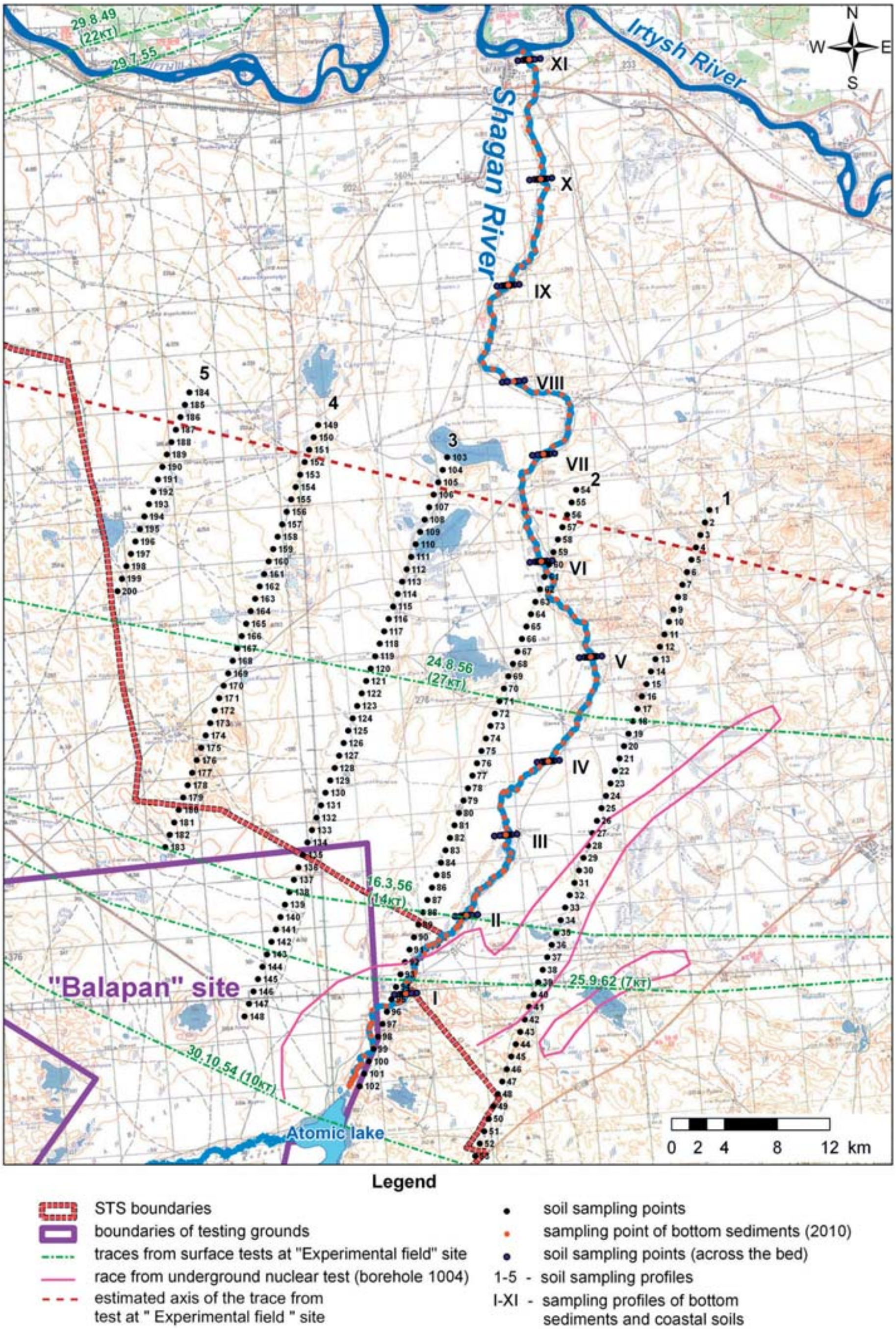


Figure 1. Soil and bottom sediments sampling scheme

2.1.1. Bottom sediments and coastal soils

The bottom sediments were sampled to obtain more detailed picture on the contamination along the river. The sampling was carried out at the points where Shagan River flows from "Atomic" Lake before the confluence with Irtysh River with spacing of 1 km. The distance between the sampling points was determined directly on site considering the river bends. The bottom sediments were sampled directly from the river-bed. If there was water in the bed, the samples were placed on a tray for pre-drying. A particular attention during the sampling was paid to maximal preservation of the samples geometry (5x10x10 cm).

To determine the concentrations of artificial radionuclides in the coastal zone and to determine the role of the contamination migration with surface watercourses, the coastal soils were sampled on perpendicular profiles crossing the bed every 10 km from "Atomic" Lake.

2.1.3. Soils

Samples of soils were taken at spacing of 1 km on 5 perpendicular profiles. The purpose of this sampling was to determine the levels of local precipitation and identification of areas where the "traces" passed.

In order to obtain data on the ratios of the radionuclides in the epicenter of the explosion, soil was sampled near the piles of the crater. To obtain the most accurate data and avoid possible external factors (erosion of the rocks and, consequently, some radionuclides with water, impact of atmospheric precipitations from other nuclear tests), samples were taken at points with the highest values of radiation parameters. At that, the sampling was carried out at a depth of 5-10 cm.

2.2. Laboratory work

Bottom sediments and soils of Shagan River valley were studied in two analytical laboratories of the NNC RK: the IRSE NNC RK laboratory for radiochemical research and Environmental Engineering Laboratory of the Institute of Nuclear Physics NNC RK.

All the measurements and analyses of environmental samples were carried out in compliance with existing state standards, ST RK, normative and methodical documents of the RK [5, 6, 7, 8, 9].

Plutonium isotopes were determined by α-spectrometry method after being separated radiochemically. Full acid decomposition of the sample was used. To account for the loss of plutonium, we injected isotope label – ^{242}Pu tracer; an α-spectrometric source was produced by electrolytic deposition. The overall chemical yield of plutonium varied in the range of 30-65%.

In this work we used an alpha spectrometer by Canberra Co. consisting of vacuum chambers, α-radiation detectors, pulse analyzer and software GENIE2000. The detection limits were calculated based on the type of sample and measurement time.

The samples for γ-spectrometric analysis were prepared in the following sequence: separation of inclusions (vegetation and stones) from the bulk of soil, drying the sample to constant weight, sieving the sample through a sieve with a cell of 2 mm in diameter, fraction abrasion less than 2 mm on a mill to size up to 200 mesh (≤0.074 mm), quartering, taking the batch weight in a vessel of calibrated geometry for measurements. The prepared samples were submitted for γ-spectrometric measurements.

Gamma-ray spectrometers manufactured by Canberra and Ortec companies, consisting of γ-radiation detector based on pure germanium, pulse analyzer and software package were employed in order to determine the contents of γ-emitting radionuclides in the environmental objects.

The relative detection efficiency of the spectrometers used for the analyses is not less than 20%. The detection limits were calculated based on the geometry of the made preparations and measurement time (Table 1).

For energy calibration of the spectrometers, a set of standard γ-sources was used, and to calibrate the geometries we used volumetric activity measures of special purpose (VAMSP) containing the following radionuclides: ^{137}Cs, ^{152}Eu, ^{241}Am.

Table 1.

Minimal detectable specific activities (MDSA)

Bq/kg					
^{137}Cs	^{241}Am	^{152}Eu	^{154}Eu	^{60}Co	$^{239+240}$Pu
0.2 - 3	0.6 - 3	1 - 4	1 - 4	1 - 4	0.2

3. RESULTS

3.1. Contamination of bottom sediments

3.1.1. Distribution of ^{241}Am, ^{60}Co, ^{152}Eu, ^{154}Eu

Distribution of artificial radionuclides in the bottom sediments of Shagan river bed is shown in the figure (Figure 2).

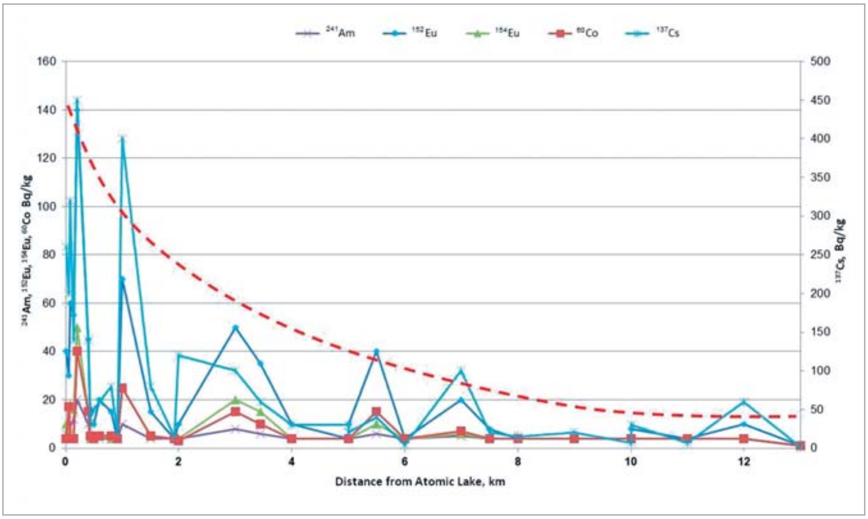


Figure 2. Distribution of artificial radionuclides in bottom sediments

The Figure 2 shows that the contents of all artificial radionuclides are maximal at the outlet from "Atomic" Lake, which is undoubtedly due to the excavational explosion in the well 1004. A decrease in the ^{241}Am, ^{60}Co, ^{152}Eu, ^{154}Eu activities close to the background values is at a segment of approximately 12 km from "Atomic" Lake; in the other part of the bed before the confluence with Irtysh River there are several points where some values not exceeding 3 Bq/kg were recorded. At that, the radionuclides concentration falls unevenly, but in the form of several distinct peaks, where the maximal concentration decreases depending on the distance to "Atomic" Lake.

Given the different migration abilities of the radionuclides, such distribution cannot be attributed to their migration with surface waters: it can be attributed to the spread of the radioactively contaminated rocks due to the explosion. To confirm this version, the ratios of the considered radionuclides in the sediments at the "peak" values and on the crest of the crater of "Atomic" Lake were analyzed (Figure 3).

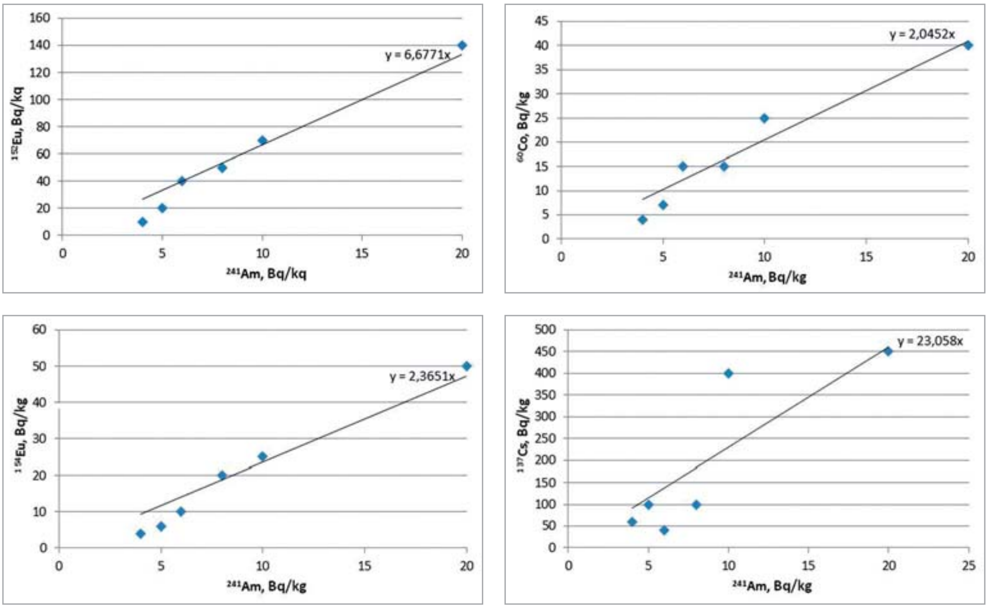


Figure 3. Certain isotopes ratios in bottom sediment samples

The table below (Table 2) presents comparative data on the average ratios of isotopes in the bottom sediments and soils of the crater crest.

Table 2.

Average ratios of the isotopes

Sampling spot	^{137}Cs	^{152}Eu	^{154}Eu	^{60}Co	^{241}Am
Bottom sediments	23.1±6.0	6.7±2.2	2.4±1.0	2.1±1.0	1
Crater crest	7.8±2.5	6.4±2.2	2.2±1.0	1.7±0.9	1
Profile 2	24.9±6.5	3.8±1.1	2.6±1.1	1.4±0.8	1

The data shown in the figure (Figure 3) and table (Table 2) confirm the assumption that the main contamination of bottom sediments of the river bed was directly caused by the explosion in the well 1004 and to date is well formed, almost unchangeable over time. It can be assumed that the major release of products from the nuclear explosion occurred exactly in the north-east direction, as evidenced by the direction of the axis of the explosion trace in the well 1004, based on archive materials. The resulting pattern of radionuclides distribution can be the basis for assessment of soil contamination in other directions from "Atomic" Lake.

According to the data shown in the figure (Figure 2), we can conclude that contamination with artificial radionuclides (activation products) is recorded at a distance of up to 12 km. A distinctive feature of this contamination is that overall pattern of the artificial radionuclides distribution does not show the widespread contamination with a monotonously decreasing concentration. With an overall picture of activity decay according to its distance from the crest of "Atomic Lake’s" crater at 0.2 km; 1.2 km; 3 km; 5.5 km; 6.5 km; 12 km, among which no artificial radionuclides were detected.

The assumption of a 12-km influence zone from underground explosion in 1004 is also evidenced by the results of laboratory testing of the coastal soil samples. Quantitative values for artificial radionuclides ^{241}Am and ^{152}Eu were obtained only at the profile I, which is 10 km from the crest of the crater (Figure 4).

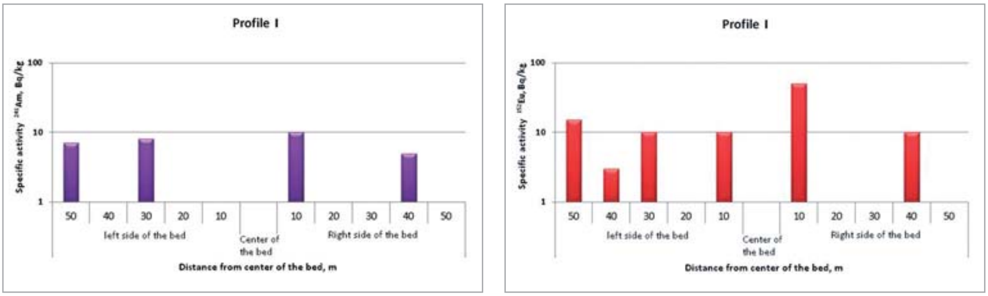


Figure 4. Distribution of ^{241}Am and ^{152}Eu in coastal sediments

3.1.2. Distribution of ^{137}Cs

Some other change in the concentrations is attributed to ^{137}Cs, whose presence is recorded throughout the streambed (Figure 5). Relation of ^{137}Cs to ^{241}Am in the sediments and crest of the crater is as different as almost 3 times. The areas with elevated concentrations of ^{137}Cs in 13-22, 43-46, 68-72 km from "Atomic" Lake are clearly seen, while in those areas there are no activation products. The zones with higher concentrations of ^{137}Cs were probably formed due to atmospheric fallout after the tests at "Experimental field" site. To confirm the above assumption, axis traces from the nuclear tests carried out at "Experimental field" site was applied on the distribution graph of ^{137}Cs in the bottom sediments.

According to the data presented in the figure (Figure 5), we can make the following assumptions:

- the peak, located at 12 km, is most likely associated with 7 kt explosion of 25.09.1962, while the width of the trace made by this explosion is in the range from 8 to 14 km and is about 6 km;

- trace axis of the explosion produced on 16.03.1956 and recorded at 20 km has a slight offset, relative to the concentration peak of ^{137}Cs falling on the 18th km from "Atomic" Lake, with a trace width of 10 km;
- the peak, located at 44 km is associated with the of 27 kiloton explosion performed on 24.08.1956 with 8 km trace width;
- the area between 64 km and 72 km has a region with several peaks, but according to available information at this time, no traces of atmospheric nuclear testing in this area passed.

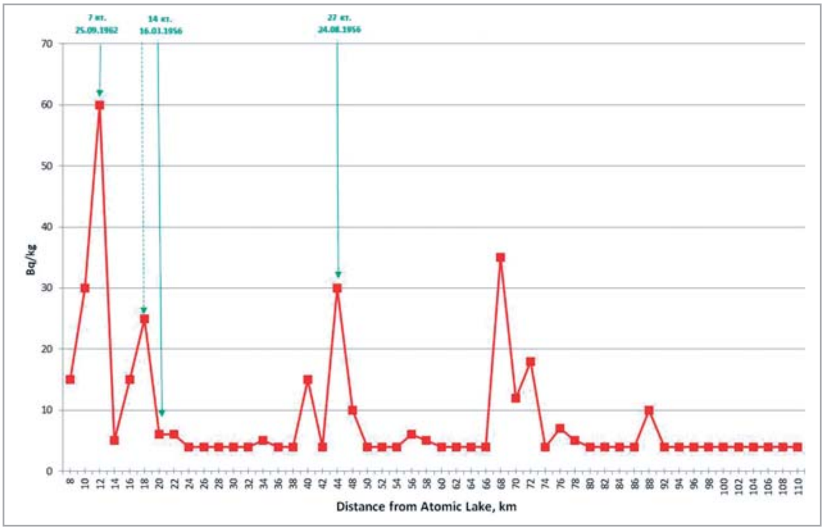
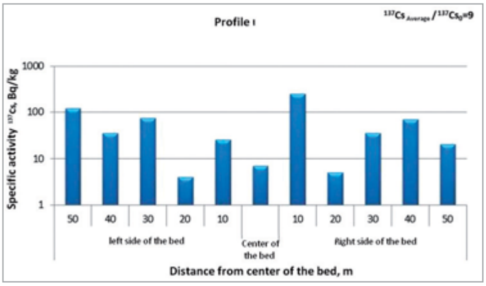
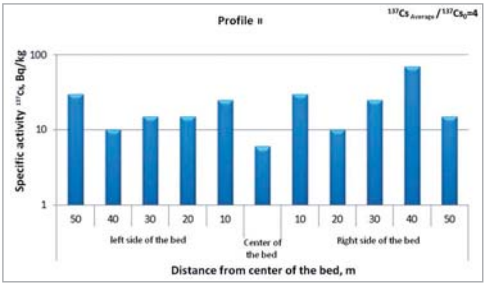


Figure 5. Distribution of ^{137}Cs in the bottom sediments

The results presented in the graph (Figure 5) highlight some features of ^{137}Cs distribution in the bottom sediments. A complete absence of ^{137}Cs (<3 Bq/kg) at some parts of the bed makes it interesting, despite the fact that the background of global fallout, according to [10] for ^{137}Cs is 4 – 29 Bq/kg. This is, apparently, associated with proliferation of radionuclides into the soil with infiltration flow. The results obtained, despite the good correlation between the axes of the traces and peaks of ^{137}Cs distribution, do not permit a statement about their relationship. Thus the maximal specific activity of ^{137}Cs in the peak is 35 Bq/kg, which is quite comparable with the background of global fallout. The peak with ^{137}Cs activity, equal to 60 Bq/kg and located at 12 km may well be related to an explosion in the well 1004.





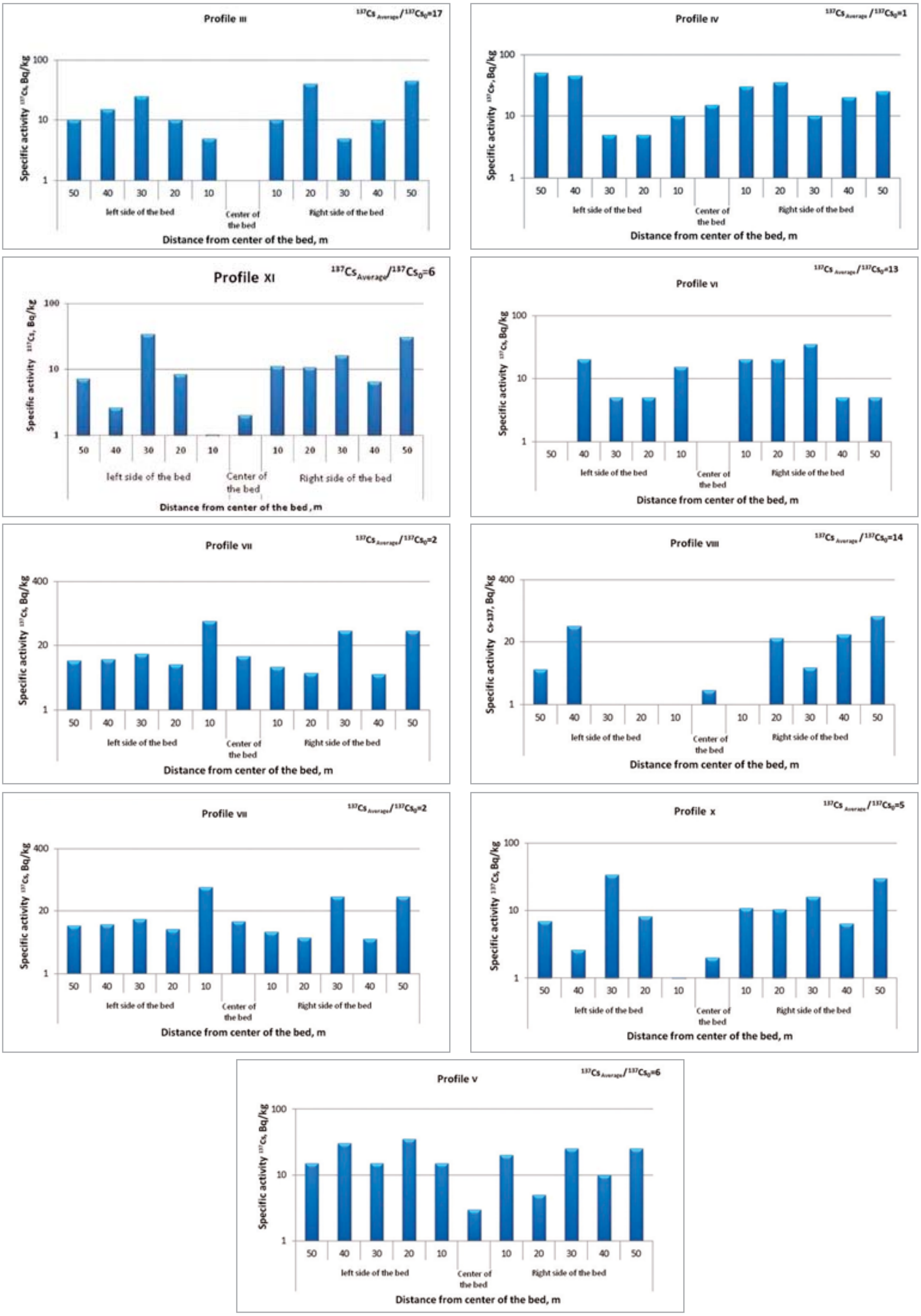


Figure 6. Distribution of ^{137}Cs in the coastal soils

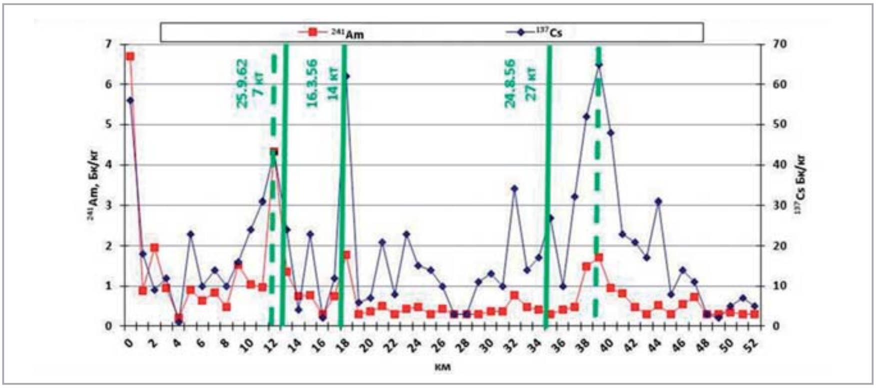


Figure 7. Distribution of ^{137}Cs and ^{241}Am on profile 1

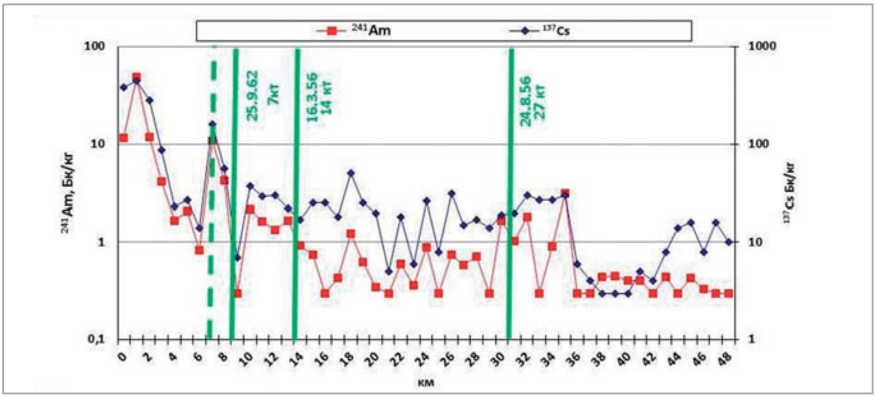


Figure 8. Distribution of ^{137}Cs and ^{241}Am on profile 2

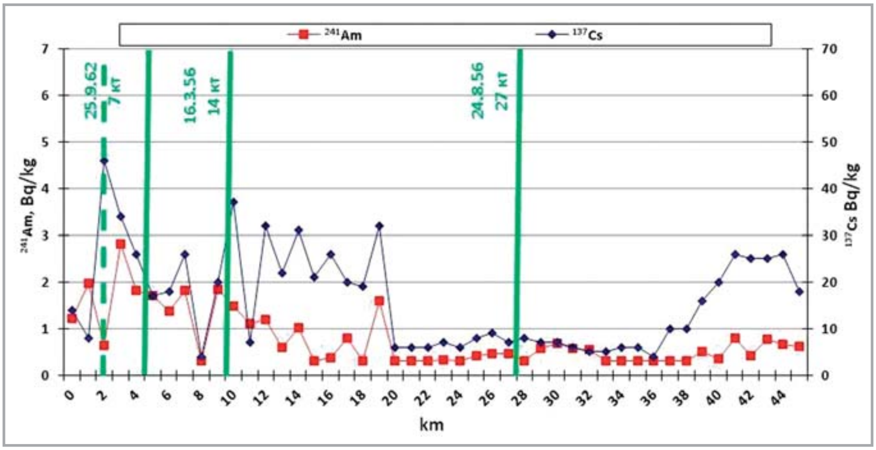


Figure 9. Distribution of ^{137}Cs and ^{241}Am on profile 3

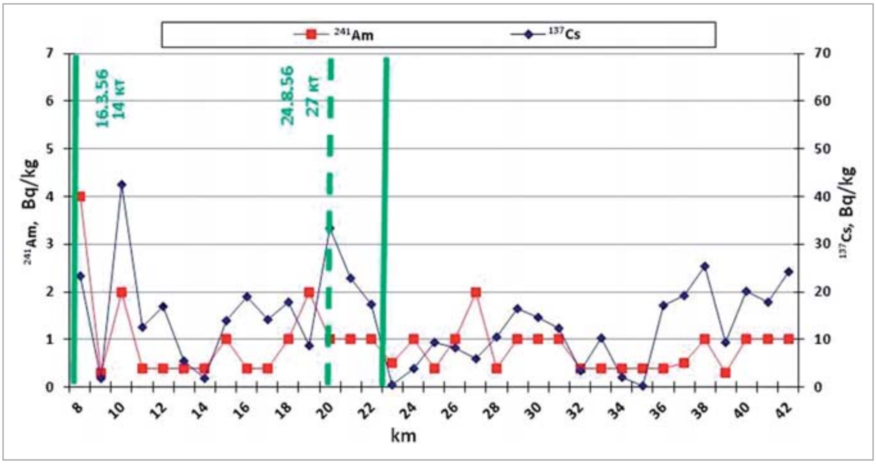


Figure 10. Distribution of ^{137}Cs and ^{241}Am on profile 4

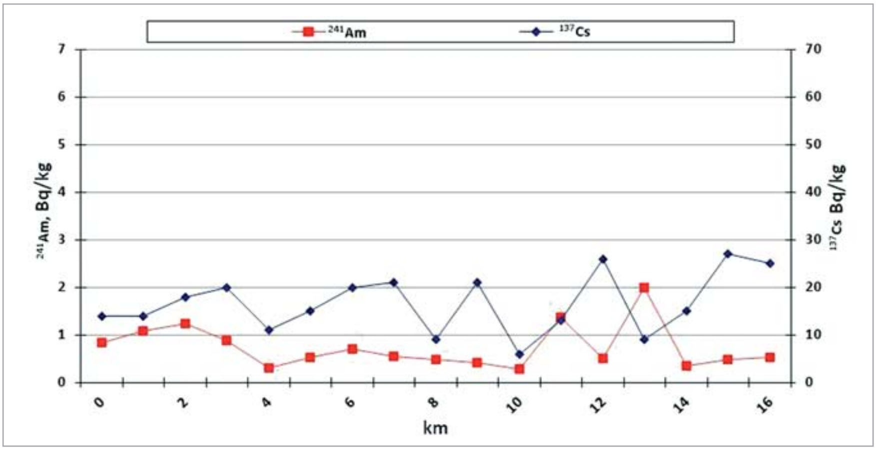


Figure 11. Distribution of ^{137}Cs and ^{241}Am on profile 5

To confirm the hypothesis on the relationship of the peaks of ^{137}Cs in the bottom sediments and traces of atmospheric nuclear tests the absolute ^{137}Cs activities in coastal soils and sediments (Figure 6) were analyzed. These data helped to assess the possible contents of ^{137}Cs in the coastline of the river. To do this, we calculated the ratio of average values of $^{137}Cs_{av}$ specific activity in the coastal soils on the profile to $^{137}Cs_0$ specific activity in the sediment on this profile.

The data obtained allowed estimating the levels of coastal soil contamination with ^{137}Cs. Thus the ratio of ^{137}Cs concentration in coastal soils to concentration of ^{137}Cs in the bottom sediments ranges from 2 to 35. At that the average value is 7. Thus, we can assume that the concentration of ^{137}Cs in coastal sediments in the peak areas could range from 70 to 2,100 Bq/kg, what is well above the background of global fallouts.

Thus, we can say with confidence that the regions with high concentrations of ^{137}Cs in the bottom sediments are associated with the axes of traces passing from "Experimental field" site.

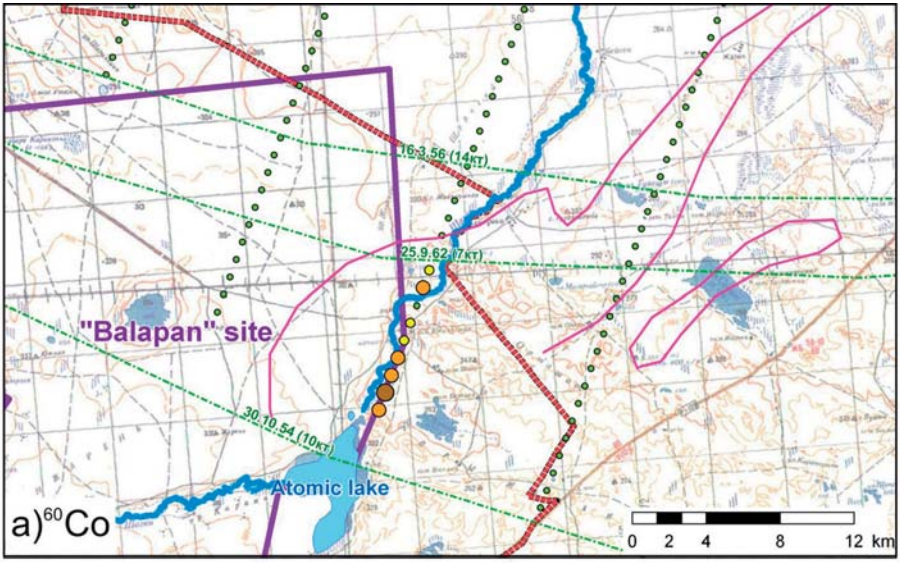
3.3. Soils

To study soil contamination the specific activities of artificial radionuclides in soils of Shagan River Valley were determined. The aim of this work was to determine the nature and mechanisms for formation of radiation environment in the studied area. It was assumed that, as with the bottom sediment, this area at least had two sources of contamination. They are excavational underground explosion in well 1004 and global fallouts from the atmospheric nuclear tests.

Distribution of ^{137}Cs and ^{241}Am on the profiles is shown in the figures (Figure 7 - Figure 11). The orientation of the profiles was taken from south to north. For convenience, while construction the graph for Profile 2 we used a logarithmic scale.

The results given in Figures (Figure 7 - Figure 11) show that the specific activity of ^{137}Cs is in a wide range of values from 1 to 500 Bq/kg, specific activity of ^{241}Am changes from 1 to 48 Bq/kg. The peaks of these radionuclides, almost everywhere, change synchronously, which may indicate the one source of origin. Applying the traces of atmospheric nuclear tests on the graphics (green solid bar) can explain the origin of peak activities of ^{137}Cs and ^{241}Am. In some cases with the data obtained, it was possible to correct axes (green dotted line) for these traces.

Determination of ^{152}Eu, ^{154}Eu, ^{60}Co activation products showed that the quantitative values were obtained only in single samples taken in the zone of "Atomic" Lake influence. The laboratory results are presented in the figure as a contamination map (Figure 12).



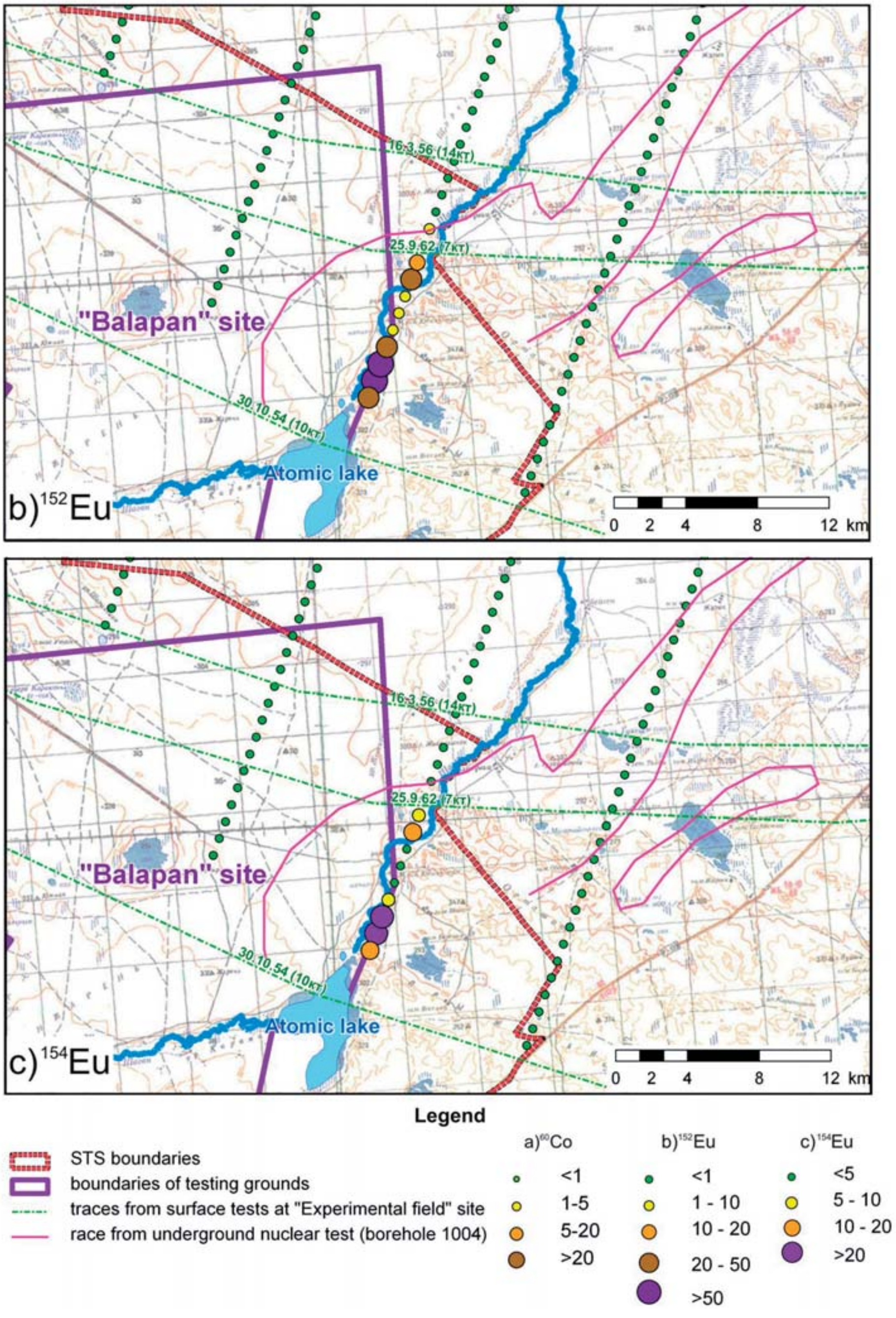


Figure 12. Map of contamination with ^{152}Eu, ^{154}Eu, ^{60}Co

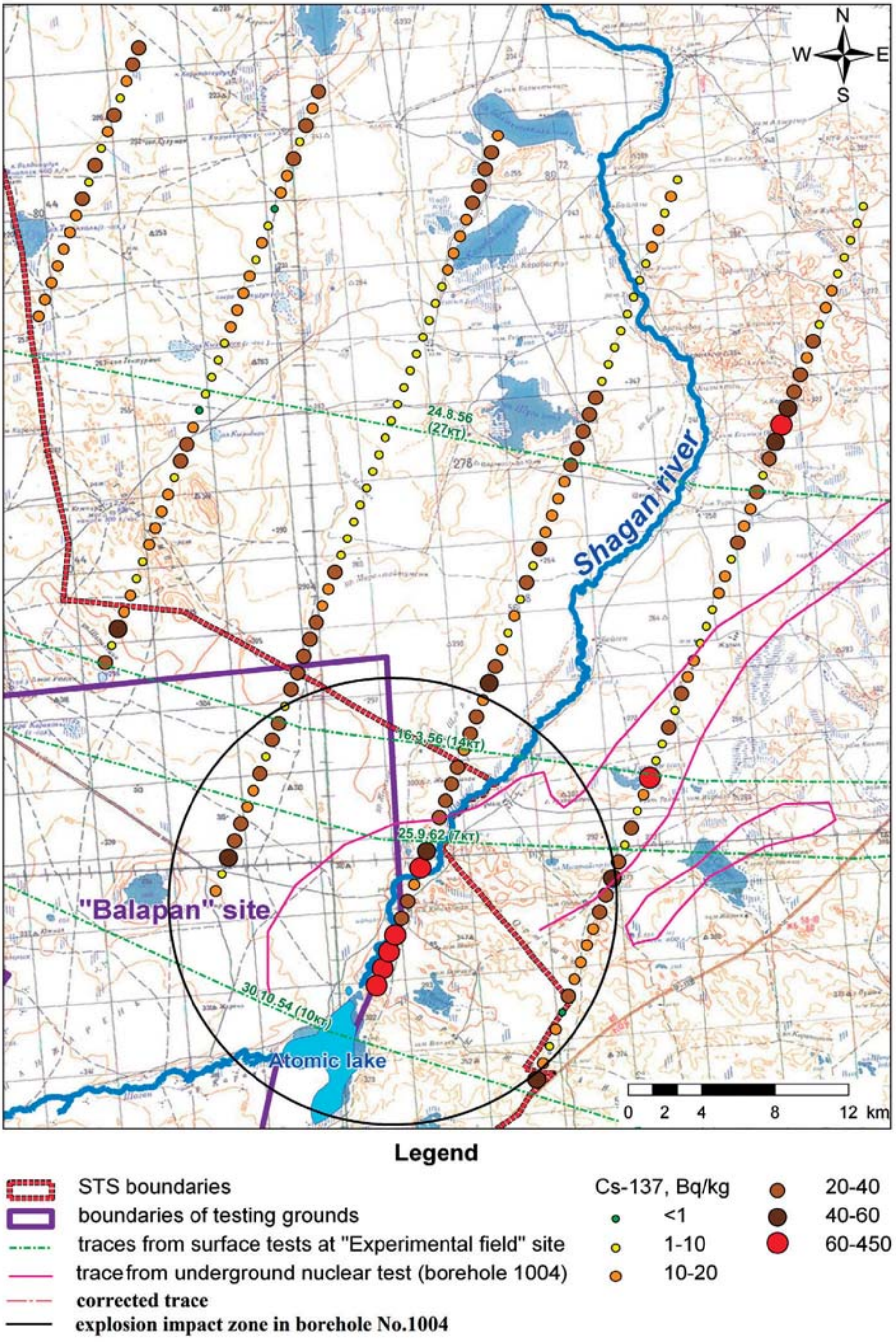


Figure 13. ^{137}Cs contamination map

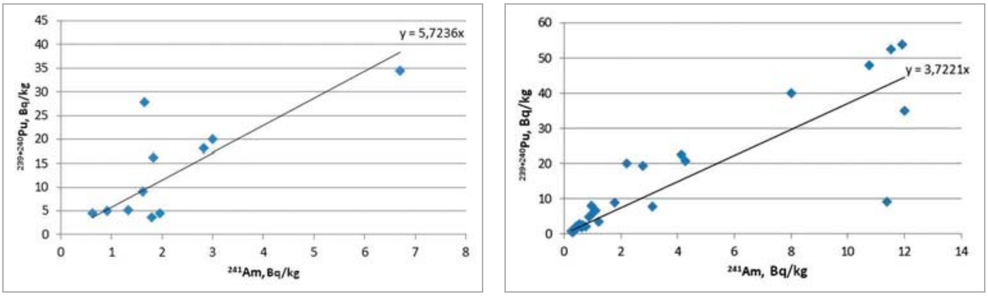
The data obtained enabled us to conclude that the source of radioactive contamination with activation product is the underground explosion in the well 1004. In this case the values obtained were: ^{152}Eu – from 0.5 to 270 Bq/kg, ^{154}Eu – from 5 to 100 Bq/kg, ^{60}Co – up to 90 Bq/kg.

Using the data obtained, levels of radionuclide contamination of soil, correction of the axes and width of the traces from ground nuclear testing were determined (Figure 13).

3.4. Contamination with plutonium isotopes

Given the considerable complexity of the traditional methods for determining $^{239+240}Pu$ (alpha spectrometry with preliminary radiochemical separation), in this study of contamination with plutonium isotopes we methodologically focused on determining the correlation between ^{241}Am and plutonium. Such an approach is quite common and is fully justified, especially if there is one source of contamination. The situation in the vicinity of "Atomic" Lake is somewhat more complicated since the contamination is combined (from several sources).

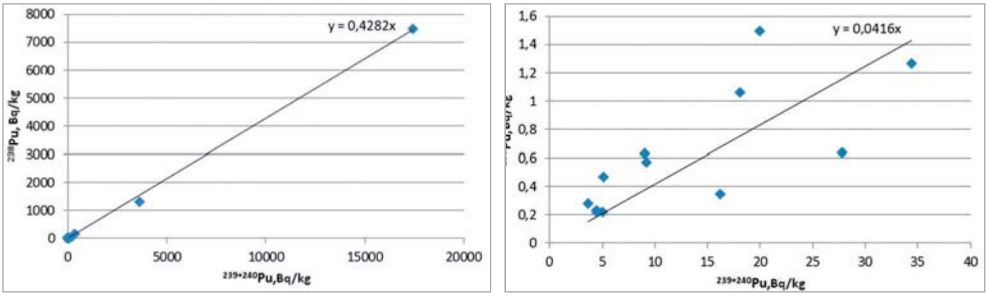
Upon data analysis on contamination with artificial radionuclides, the results of laboratory tests to determine the plutonium isotopes were divided into two groups. The first group included the results of laboratory analysis of samples taken within the zone of "Atomic" Lake influence and the second - all the rest. The ratio graph of $^{239+240}Pu/^{241}Am$ was plotted (Figure 14).



a) "Atomic" Lake zone   b) Rest of the territory

Figure 14. Ratio of $^{239+240}Pu/^{241}Am$ in various areas

Thus, we managed to get two ratios of $^{239+240}Pu/^{241}Am$ which confirmed the theory about the two sources of contamination. Another parameter that allows identifying the origin of artificial radionuclides is the ratio of $^{238}Pu/^{239+240}Pu$. For the same source this ratio should be approximately the same. Dotted diagrams of $^{238}Pu/^{239+240}Pu$ ratios (Figure 15) were constructed for the groups above.



a) "Atomic" Lake zone b) Rest of the territory

Figure 15. Ratio of plutonium isotopes $^{238}Pu/^{239+240}Pu$

As a result, for the "Atomic" Lake zone we have $^{238}Pu/^{239+240}Pu$ ratios equal to 0.4, which is confirmed by examination of samples taken from the epicenter of the crater, wherein the ratio is 0.39. For the rest of the territory the $^{238}Pu/^{239+240}Pu$ ratio is equal to 0.04, which is approximately equal to the ratio obtained during the examination of the "northern" part of the STS, where this ratio was 0.02–0.03 [10].

Thus, at conservative estimate of plutonium contamination in the studied area on the correlative relationship with ^{241}Am, the following input data may be used. For the territory bounded by a radius of 12 km, i.e. of "Atomic" Lake influence zone the $^{239+240}Pu/^{241}Am$ ratio can be taken as 2.5, and for the rest of the territory it will be equal to 5.7.

4. CONCLUSION

The findings of these studies allowed assessing and determining the mechanisms for radioactive contamination of Shagan River valley. The sources of contamination are global fallouts, fallouts from the tests at "Experimental field" site, excavational underground explosion in the Well 1004.

Virtually over the entire territory we revealed ^{137}Cs, ^{241}Am caused by the global fallouts, at a level of up to 30 Bq/kg. The main contribution to the contamination of Shagan River valley was made by the fallouts from tests at "Experimental field" site, excavational explosion in the Well 1004, which formed two zones of radioactive contamination.

The first zone is the result of nuclear testing with soil outburst and has a relatively small radius of about10-12 km from the crest of the "Atomic" Lake crater; at that, the maximal contamination is observed in the north-eastern direction over the assumed pass of the explosion cloud. It is characterized by the widespread activation products ^{60}Co, ^{152}Eu, ^{154}Eu. The $^{238}Pu/^{239+240}Pu$ ratio for this territory comprises 0.4, $^{239+240}Pu/^{241}Am$ – 5.7.

The second zone was contaminated due to the fallouts from the tests at "Experimental field" site. Basically, this territory has areal contamination with ^{137}Cs, ^{241}Am, which are spatially confined to the traces from the nuclear surface explosions at "Experimental field" site having a width of about 10 km. $^{238}Pu/^{239+240}Pu$ ratio for the area will be equal to 0.04, $^{239+240}Pu/^{241}Am$ – 5.7.

Thus, the radiological situation at these lands has been formed by now. The works revealed the virtual absence of artificial radionuclides migration with surface waters, and concerns about possible cross-boundary transfer of radionuclides ^{60}Co, ^{152}Eu, ^{154}Eu with the waters of rivers Irtysh and Shagan are not confirmed.

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REFERENCES

1. Peaceful nuclear explosions: ensuring basic and radiation safety / V. A. Logacheva. [in Russian]
   Мирные ядерные взрывы: обеспечение общей и радиационной безопасности при их проведении / под ред. В.А. Логачева. - М., 2001. - 519 с.
2. Radiological assessment of the situation and monitoring at the Semipalatinsk test site and surrounding regions. "The development of environmental protection measures: 01.01.01.n. Stage: "Assessment of radioecological situation at the test site Balapan": A Report on R & D. [in Russian]
   Оценка радиологической обстановки и мониторинг на территории Семипалатинского испытательного полигона и прилегающих к нему регионов". Разработка природоохранных мероприятий шифр темы: 01.01.01.н. Этап: "Оценка радиоэкологической обстановки на испытательной площадке "Балапан: отчет о НИР (заключительный) / рук. Л.Д. Птицкая. – Курчатов: ИРБЭ НЯЦ РК, 2003. -109с.
3. A. O. Aidarkhanov. Ecosystem of Shagan River and major mechanisms for its formation / A. O. Aidarkhanov, S.N. Lukashenko, S.B. Subbotin, V.I. Edomin, S.V. Genova, A.V. Toporova, N.V.Larionova, E.Yu. Pestov // Topical Issues in Radioecology of Kazakhstan [Proceedings of the Institute of Radiation Safety and Ecology for 2007-2009]. [in Russian]
   Айдарханов А.О. Состояние экосистемы р. Шаган и основные механизмы его формирования /А.О. Айдарханов, С.Н. Лукашенко, С.Б. Субботин, В.И. Эдомин, С.В. Генова, А.В. Топорова, Н.В. Ларионова, Е.Ю. Пестов // Актуальные вопросы радиоэкологии Казахстана [Сборник трудов Института радиационной безопасности и экологии за 2007 – 2009гг.] / под рук. Лукашенко С.Н. – Вып. 2. – Павлодар: Дом печати, 2010. – С. 9-54. - ISBN 978-601-7112-28-8.
4. STATE STANDARD 17.4.3.01-83 Nature Conservancy. Soil. General requirements for sampling. [in Russian]
   ГОСТ 17.4.3.01-83 (СТ СЭВ 3847 – 82) Охрана природы. Почвы. Общие требования к отбору проб. – Введ. 1984-01-07. – М.: ГСС ССР, 1983. – Инв. № 19/а.
5. STATE STANDARD 17.4.4.02.84. Methods for sampling and sample preparation for chemical, bacteriological, helminthological analysis. [in Russian]

ГОСТ 17.4.4.02-84. Методы отбора и подготовки проб для химического, бактериологического, гельминтологического анализа. - Введ.1986-01-01. // Сборник. Охрана природы. Почвы. – М.: Изд-во стандартов, 1998. –С.48-54.

6. STATE STANDARD 17.4.4.02-84 Methods for sampling and sample preparation for chemical, bacteriological, helminthological analysis. [in Russian]
   ГОСТ 17.4.4.02-84 Почвы. Методы отбора и подготовки проб для химического, бактериологического, гельминтологического анализа
7. Water quality – Determination of tritium activity corresponding to a given concentration - Liquid scintillation counting method. The international standard ISO 9698:1989 (E)
8. Guidelines for the control methods. Radiation monitoring. Strontium-90 and cesium 137. Food products. Sampling, analysis and evaluation of hygiene. ICB № 5.05.009.2000. Ministry of Health of the Republic of Kazakhstan, 2001. [in Russian]
   Методические указания по методам контроля. Радиационный контроль. Стронций-90, цезий-137. Пищевые продукты. Отбор проб, анализ и гигиеническая оценка. МУК №5.05.009.2000. Министерство здравоохранения Республики Казахстан, 2001 г.
9. Activity of radionuclides in bulk samples. The method for measurement on the gamma - spectrometer: MI 2143-91. [in Russian]
   Активность радионуклидов в объемных образцах. Методика выполнения измерений на гамма - спектрометре: МИ 2143-91. - Введ. 1998-06-02. - Рег. № 5.06.001.98. – М.: НПО ВНИИФТРИ, 1991. - 17 с.
10. Method for measurement of activity of radionuclides plutonium-(239+240) in counting samples prepared from the environmental samples. - Moscow: Federal State Unitary Enterprise "NPO V.G. Khlopin Radium Institute". [in Russian]
    Методика выполнения измерений активности радионуклидов плутония-(239+240) в счетных образцах, приготовленных из проб объектов окружающей среды. - М.: ФГУП "НПО Радиевый институт им. В.Г. Хлопина".
11. Topical Issues in Radioecology of Kazakhstan [Semipalatinsk Test Site: Radioecological Situation in the "northern" lands]. [in Russian]
    Актуальные вопросы радиоэкологии Казахстана [Радиоэкологическое состояние "северной" части территории Семипалатинского испытательного полигона] / под рук. Лукашенко С.Н. – Вып. 1. – Павлодар: Дом печати, 2010. – 234с. - ISBN 978-601-7112-28-8

ШАҒАН ӨЗЕНІ АЙМАҒЫНДАҒЫ ҚҰМДАҚТОПЫРАҚТАР МЕН ТҮПТІК ШӨГІНДІЛЕРДІҢ БЕТКІ ЛАСТАНУЫНЫҢ ҚАЛЫПТАСУ МЕХАНИЗМДЕРІН ЗЕРТТЕУ

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Шаған өзені бұрынғы Семей сынақ полигоны (ССП) шектеріндегі жалғыз жерүсті суағыны болып табылады. Техногенді радионуклидтердің жерүсті суларымен ұзақ арақашықтыққа болжамды жылыстау, яғни, Ертіс өз. түсу мәселелерін зерттеу үшін Шаған өз. алқабында тиісті зерттеулер жүргізілді. Жүргізілген зерттеу нәтижелерінде құмдақтопырақтардың радиоактивті ластануы, ең бірінші, "Балапан" алаңында 1004 штольняда жүргізілген топырақ шығарындысы бар алғашқы жерасты ядролық сынаққа байланысты екендігі анықталды. "Тәжірибе даласы" алаңында жүргізілген жерүсті ядролық сынақтар, ауқымды түсулер ластануға аздаған үлес қосты. "Атом" көлі шұңқырына тікелей жақын телім аса ластанған болып табылады. Аталған телімдегі ластану алаңдық сипатқа ие. Ластанудың жалпы алаңы шұңқырдың ернеуінен 10-12 км шектелген. Плутоний изотоптарының арақатынасы құмдақтопырақтардың ластану көздерін анықтау үшін жақсы идентификациялық параметр болатыны анықталды. Түптік шөгінділердің зертханалық талдамасы "Тәжірибе даласы" алаңындағы ядролық қару сынақтары іздерінің орналасуын анықтап, түзетуге мүмкіндік берді. Жұмыстар процесінде техногенді радионуклидтердің жерүсті суларымен жылыстауының іс жүзінде жоқ болуы анықталды, және радионуклидтердің Шаған және Ертіс өзендерінің суларымен болжамды трансшекаралық тасымалдануы туралы қауіп расталмайды.

Түйін сөздер: ядролық сынақтар, "Атом" көлі, жерүсті радиоактивті ластану, радионуклидтер, қалыптасу механизмдері, жылыстау.

ИССЛЕДОВАНИЕ МЕХАНИЗМОВ ФОРМИРОВАНИЯ ПОВЕРХНОСТНОГО ЗАГРЯЗНЕНИЯ ПОЧВОГРУНТОВ И ДОННЫХ ОТЛОЖЕНИЙ В ЗОНЕ РЕКИ ШАГАН

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Река Шаган является единственным поверхностным водотоком в пределах бывшего Семипалатинского испытательного полигона (СИП). Для изучения вопросов возможной миграции техногенных радионуклидов с поверхностными водами на значительные расстояния, а, следовательно, попадания в р. Иртыш, были проведены соответствующие исследования в долине р. Шаган. В результате проведенных исследований было установлено, что радиоактивное загрязнение почвогрунтов, в первую очередь, обусловлено первым подземным ядерным испытанием с выбросом грунта, проведенным на площадке "Балапан" в скважине 1004. Незначительный вклад в загрязнение внесли наземные ядерные испытания, проведенные на площадке "Опытное поле" и глобальные выпадения. Наиболее загрязненным является участок в непосредственной близости от воронки "Атомного" озера. Загрязнение на данном участке носит площадной характер. Общая площадь загрязнения ограничена 10 – 12 км от гребня воронки. Выявлено, что хорошим идентификационным параметром для определения источника загрязнения почвогрунтов является соотношение изотопов плутония. Лабораторный анализ донных отложений позволил выявить и скорректировать положение следов от испытаний ядерного оружия на площадке "Опытное" поле. В процессе работ установлено практическое отсутствие миграции техногенных радионуклидов с поверхностными водами, и опасения о возможном трансграничном переносе радионуклидов с водами рек Шаган и Иртыш не подтверждаются.

Ключевые слова: ядерные испытания, "Атомное" озеро, поверхностное радиоактивное загрязнение, радионуклиды, механизмы формирования, миграция.

PART: RADIOECOLOGY OF OTHER TEST VENUES AND FACILITIES IN KAZAKHSTAN

УДК 577.4:504.064:539.16

REMEDIATION OF NUCLEAR TEST CONSEQUENCES AT AZGIR TEST SITE AND ITS CURRENT RADIOLOGICAL CONDITIONS

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The paper provides an overview of the works on creation of underground cavities at "Azgir" test site, describes parameters of nuclear explosions, state of wells and underground cavities. Basic mechanisms for possible migration of radionuclides into the environment were examined. Based on the results from radioecological studies and continuous monitoring data, it is shown that current radiological situation at the test site and in surrounding villages do not go beyond the established sanitary standards. A conclusion was made about effectiveness of the techniques and technologies used to reduce radiation risks.

1 PHYSICAL AND GEOGRAPHIC PECULIARITIES OF THE REGION

1.1. Geographical location

Azgir test site is located in the territory of the former state farm "Balkuduk", administratively is a part of the Kurmangazy district of Atyrau Region of Kazakhstan. The nearest railway station Kharabalinskaya (Astrakhan Region of RF) is situated 75 km from the site. The site is located in semi-arid area on the outskirts of the Ryn-Peski Desert, where there are rare farms and sheepyard. To the east at a distance of 400 km is Taysoygan test site, north at a distance of 250 km – Kapustin Yar test site, in south at a distance of 60 km – Ashuluk test site. Geographical features of the region are relative proximity of the Volga and the Caspian Sea. The road network consists of dirt roads connecting all villages with each other, which in the rainy season become impassable. All sites are interconnected by country roads.

1.2. Topography

The territory is characterized by flat plain elevated 10 to 20 m above sea level (except for arrays of ridged and hilly sands).

Relief of the site – poorly hilly steppe plain, mostly occupied by sand arrays, represented by poorly fixed sand dunes and mounds 3-5 m in height, giving the area a more undulating and barren nature. Uplift at Chapchachi Mountain (reaching a height of 60 m) is characterized by deeply desiccated profile.

The entire territory is characterized by micro-relief, which creates unequal hydroclimate and microclimatic conditions for soil formation, causing complexity of the soil cover.

1.3. Climate

By its natural conditions the territory is classified as desert. Its climate is shaped under predominant influence of the Arctic, Iranian and Turanian air masses. During winter period, the land form is dominated by cold arctic masses, in summer they move as overheated masses from the deserts of Central Asia and Iran. These masses in the region shape harsh continental and dry climate.

The average annual temperature based on the long-term data of meteorological stations of the regional Centre is equal to +7.4°C. Average temperature in July - +25.1°C, in January - –10.7°C. Absolute maximum - +45°C and minimum - –42°C. The average annual range of air temperature is 35.4°C.

Annual rainfall amount is 157 mm, during warm period (April-October) – 100 mm, during cold season – 57 mm. Most rain falls in spring. Cold season is dominated by winds of eastern and south-eastern directions, starting in May, they shift to west and north-west. Average wind velocity is 5-7 m/sec, number of days with strong winds (over 15 m/sec) reaches over 55 days a year.

1.4. Soils

The territory of "Azgir" belongs to the subzone of the northern deserts and is characterized by brown soils shaped in harsh continental climate and saline parent material [1].

Features of these soils are:

- low humus content, both in upper layer and whole profile;
- alkalinity inherent in varying degrees to almost all varieties of soil;
- widespread light texture soils, which is associated with dominance in the area of parent light texture rock. The soils of the described territory are characterized by pronounced complexity.

1.5. Vegetation

Floristically the area is rich and has 160-170 species of flowering plants belonging to 22 families. The most widely spread both for the number of its constituent species and for its role in shaping the vegetation is family of Compositae. Wormwood is one of the major plants in this family. Significant role in shaping the vegetation belongs to family of cereals. The species of this family – the most valuable fodder plants that along with wormwood form the foundation fodder reserves of pastures. Family of pigweeds is widely distributed in the area. Ephemera and ephemeroides play a significant role in forming the vegetation in spring and autumn. According to the results of botanical surveys 18 types of pasture and 39 modifications, combined in 14 groups were distinguished. Severe climatic conditions, lack of moisture and lack of fodder cause utilization of the area as seasonal grazing for distant-pasture cattle tending. But at the same time a lot of heat and a long growing season allow cultivating the valuable heat-loving plants under irrigation.

2. GEOLOGIC STRUCTURE

The salt-dome structure Great Azgir consists of two geological formations: West Azgir salt dome, where A1 and A2 sites are located, and Azgir East salt dome, within which there are other technological sites of the former "Azgir" test site. Geologically the two formations constitute a single complex.

Salt-dome structure Great Azgir is composed of Paleozoic, Mesozoic and Cainozoic sediments. The most ancient sediments are the Lower Permian halogenous and sulphate-halogenous complexes. Thick sulphate-halogenous thickness plays an active role in the salt tectogenesis. The overlying Upper Permian and younger sediments are part of the single suprasalt complex. Covering Pleistocene sediments are widespread and are represented by both marine and continental formations of various geneses. In the suprasalt complex there are breaks and stratigraphic unconformities expressed in terms of transgressive overlap.

No outputs of tectonic and plication dislocations to the surface in other parts of the described area are observed. On the hollow-bored submerging northern wing of the southern brachyanticline manifestation of salt-dome tectonics are less intense than in the cragged hollow-bored submerging in the south.

The salt domes of East and West Azgir limit the structure from the west and east. These are the second-order structural highs, elongated in the sub-meridional direction for about 15 km with a width of 7-8 km. The compensation glacial trough Uzhantator is brachysyncline having round shape. A rock-salt lies at the core of the structure. The roof of subsalt sediments is at a depth of about 7,000 m.

The west dome is open – in the south-eastern part the rock salt lies directly at the surface, reaching the absolute height plus 5 m - 6 m; it is the highest point of the dome, so-called mountain Chapchachi. Hence, the salt massif gently immerse in a northerly direction and very steeply to the south. The west wing of the massif is relatively gentle, the eastern is steeper, and the steepness of the latter increases significantly in the south.

The East dome is closed – rock salt here everywhere is overlain by quaternary formations. At the crest of the dome the rock salt reveals at depths of 238 m (well A10) – 347 m (well A5).

It is assumed that rock salt will distribute in the range of compensation trough Uzhantator, which is the negative homolog of salt domes East and West Azgir. This is evidenced by the continued plunge at the rate equal to the rate of growth of the highest points of the West dome.

The orientation of the salt layers within the massif, in general, is consistent with its configuration. The salt massif together with suprasalt rocks have tectonic contacts formed during the growth of diapir. The suprasalt rocks fall away from the salt massif, usually at angles less than the fall of the wings of the latter. The tensile stresses developed in the thick subsalt rocks in the process of raising the diapir, led to formation of disjunctive dislocations. At that, the degree of rocks diversity is determined by the remoteness of them from the surface of the salt massif and intensity of salt-dome tectonics occurrences in the area. The clear traces of the tectonics occurrence are practically of all suprasalt occurrences – from Kungurian gypsum-anhydrite rock mass to the lower Khvalynskiy clays inclusive.

The territory belongs exclusively to the water-dependent area. There are no surface waters (rivers, lakes) available, in this connection the groundwater is of exceptional value.

The fresh waters occur in the form of "floating lentil" in hard salted waters and in case of their immoderate use the wells yield salty water, mineralization of which reaches 15g/l–18g/l, by salt composition the sodium chloride and sodium sulphate groundwater dominate.

The wells with the highest water inflow are located in villages and sheepyard: Azgir, Batyrbek, Algabas, Karagayte, Akkuduk, Balkuduk, and Assan. These wells uncover relatively small lenticular aquifers with fresh or saltish waters hosted by Quaternary and Neogene (Apsheron) deposits.

The hydrogeological conditions of Azgir area is due to geology, tectonic and geomorphic situation in the described area, its location in the continental salinization area, lack of fresh water and slow flow rates of groundwater.

The following horizons and complexes are highlighted below:

- The water-bearing formation of Khvalynskiy sediments (Q_{III}hv) is widespread in the eastern and western parts of the site, wedging to the central zone of salt-dome uplift. The occurrence depth and thickness increase toward the west and east of the central part of the site. The aquifer is free-flow. The depth of the groundwater level is determined by geomorphological features and varies from 2 m to 15 m, increasing to the central part of the site. Filtration coefficient is in the range 0.14-0.16 m/ day. Recharge of the Khvalynskiy aquifer is due to infiltration of atmospheric precipitation.
- The aquifer of the Khazar sediments (Q_{II}hz) in the eastern part of the salt dome uplift West Azgir lies below the water-bearing formation of Khvalynskiy sediments and confined to the maritime formations represented by pulverescent and, less commonly, fine-grained sands. The depth of their occurrence reaches 80-90 m, increasing toward the east. Exposed thickness of water-bearing rocks is 19 m (well 1082). The aquifer is subartesian, elevation of the water head in well 1082 is 90 m and the piezometric level was set at a depth of 1 m. The filtration properties of water-bearing rock are poorly impermeable. The aquifer is recharged by both the overflow from the aquifer of Khvalynskiy sediments, and from the underlying horizons of Neogene sediments.

The aquifer system of Neogene deposits is distributed almost everywhere, except for the West Azgir uplift. The depth of the water-bearing sands of the roof varies very widely - from a few meters up to 500 meters at the periphery of the site. Underground water is subartesian; depth of piezometric level varies from 15 m to 60 m. The aquifer is recharged outside the area, and in places where the Neogene formations go out to the surface.

The aquifers of cretaceous ($_{K1}+_{K2}$), Jurassic (J), Permo-Triassic ($_{P2-P1}$), Kazan and Ufa ($_{P2}kz+_{P2}uf$), Kungur ($_{P1}kg$) deposits have sporadic distribution, covered over with clay impermeable rocks, have high mineralization, are not used in business activities, and therefore cannot serve as a transfer agent for artificial radionuclides.

The subterranean discharge in the form of an ascending filtration is shown in the zone of salt domes and anticlines, as well as everywhere through series of impermeable rocks. It is enhanced by high reservoir pressure and temperature, which increases the permeability of the reservoir rocks and clay layers.

As a result, we can conclude that the hazardous in terms of contamination with radionuclides are underground fresh water of the first aquifer at depths from 1.5 m to 15 m (Figure 1), which can be used by local people for utility and drinking water supply, therefore it is essential to focus primarily on the monitoring of this particular aquifer, at the same time not losing sight of the quality control of the underlying groundwater aquifers and complexes at depths up to 90 m.

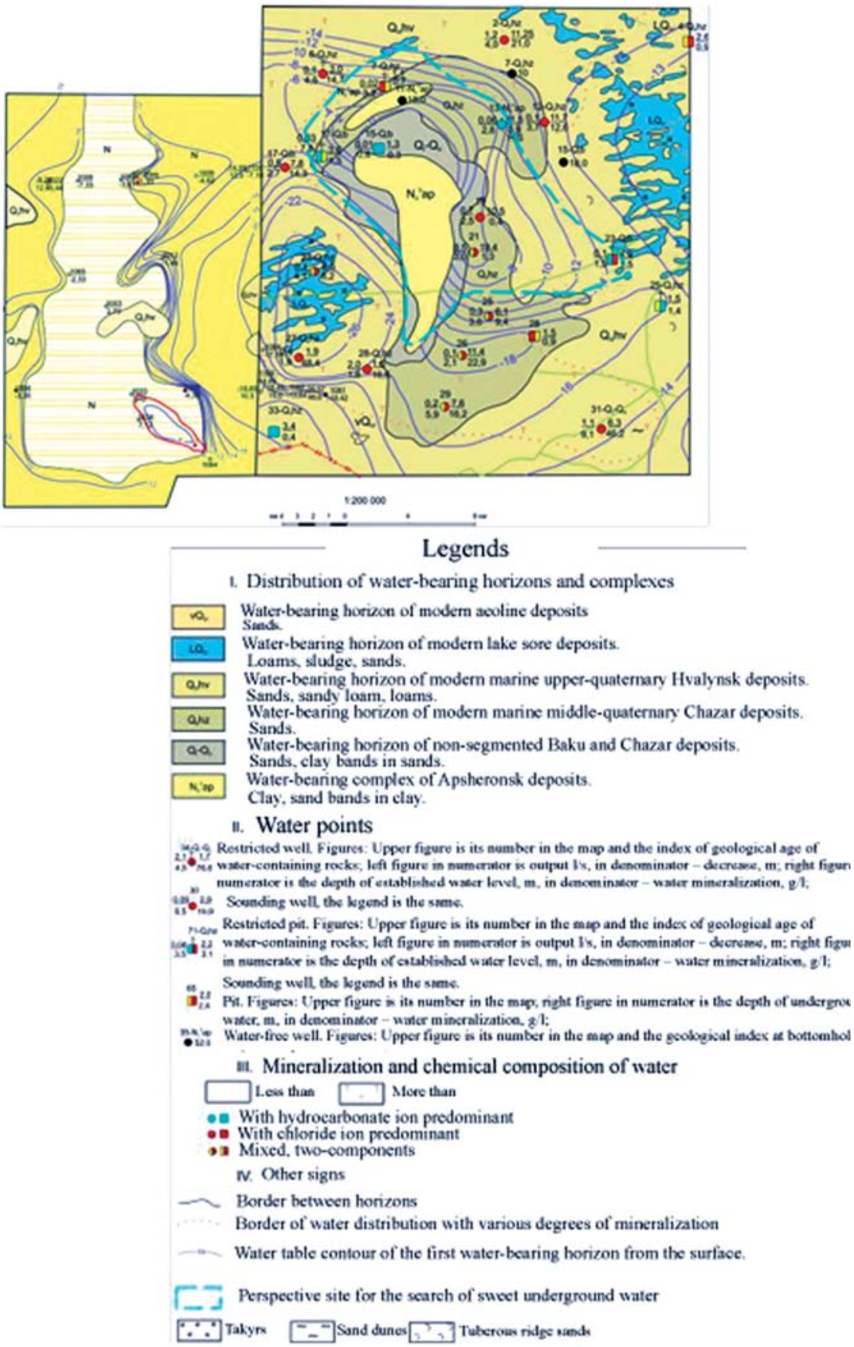

Figure 1. Schematic hydrogeological map of Great Azgir area

3. DESCRIPTION AND CHARACTERISTICS OF NUCLEAR EXPLOSIONS. WELLS AND UNDERGROUND CAVITIES

3.1. Basic information about underground nuclear explosions (UNEs)

The underground nuclear explosions were carried out to prove-out the technology of underground cavities creation in the arrays of rock salt – construction of multi-purpose high capacity storages. Other small scope experiments were carried out: decoupling - study of seismic effects and generation of transplutonium elements. Total 17 underground nuclear explosions with various yields were carried out at depths from 161 to 1,491 m during the period from 22.04.1966 to 24.10.1979 in 10 wells; this formed nine cavities of different sizes (from 10,000 m^3 to 240,000 m^3) and a losing crater with a depth of 30 m and a diameter of 500 m^2 [2]. At the A9 site the well significantly deviated from the vertical and at the working depth of 630 m (charge placement) came close to the edge of the salt-clay on the slope of the dome, so most of the explosion energy after repercussion from the salt body formed an unsteady cavity at the junction of the salt and clay arrays after the collapse of which a losing crater was formed, filled with 20,000 m^3 rain water and flood, connected to underground aquifers [3], i.e. the reservoir is partially recharged by groundwater.

Cavities A1÷A5 are filled with water, cavities A8 and A11 are dry, cavities A7 and A10 are partially filled with water. Cavities A7, A8, A10 and A11 were formed by multiple explosions – simultaneous detonation of several charges. A5 cavity at a depth of ~1500 m was created to study stability of the storages at maintaining their constant opposite pressure. In addition in A2 cavity six nuclear tests were carried out.

All the explosions were designed as camouflet, i.e. with no release of explosion radioactive products to the surface. However, it is not possible, as evidenced by data about duration of radioactive noble gas releases from the cavities – from several days to several months and their total activities up to $10^{17}÷10^{18}$ Bq. The total activity, being in the underground cavities, is 0.5÷1.0 million Ci. With the opening of the cavities 10 million Ci of radioactive gases were released into the atmosphere.

Geographical coordinates, parameters of the explosions, characteristics and condition of the wells and cavities at Azgir test site are presented in Table 3.1.

All the carried out explosions in the array of rock-salt formed different size sealed cavities, been existing for more than two decades. The exceptions were:

- - Cavity A5: pressure tight, compressible, specifically created to test theoretical assumptions about crust formation at great depth of cavities in an array of rock salt due to a sharp increase in its ductility at high pressures;
- - Cavities A1, A2, A3 and A4: stable, permeable.

Based on data about release of radioactive gas emissions to the surface, flow of groundwater in cavities A1 and A2 began in the first hour after the explosion. Their filling stopped: A1 – 20 days later, A2 – 9 days later. In accordance with the work program brine was specially injected into some of the cavities – cavities A3 - A5.

Table1.

Some parameters of nuclear explosions and condition of wells and cavities at Azgir test site

Site index (wells, cavities) geogr. coordinates degre./min. n.lat. degre./min. e.lon.	Development wells			Cavities and their state		Techno. wells	Observation wells
	Date of the 1st experiment / years of the following (q-ty of explosions)	∅ in clear, mm/depth, m/ Yield of 1st explosion, kt/distan. from charge: to salt roof/to aquifer	Duration of radioactive gases emission into atmosphere, total release, 37 GBq	∅, m/volume, thous. m^3/ amounts. act. α-radiat. in cavity, 37 GBq		∅ in clear, mm/ depth, m /q-ty, pcs.	Notation/ ∅ of casing pipes, mm
A1 / 47 / 49,75 47 / 56,00	22.04.66	820/161/1,1 160/160	20 days, $1.9*10^5$	31/14/79	3B	168/510/16	A1-1 / 219 A1-2 / 219 A1-3 / 219
A2 / 47 / 54,43 47 / 54,58	01.07.68 / 75(1) 77(2) / 78(2) / 79(1)	630/597/27 300/410	9 days, $5.4*10^6$	64/140/1500	3B	630/600/2	A2-1 / 219 A2-2 / 219
A3 / 47 / 53,76 48 / 07,91	22.12.71/1976 (1)	820/986/64 730/790	9 days, $5.4*10^6$	78/250/420	3B	820/1000/1	
A4 / 47 / 52,27 48 / 08,25	29.07.76.	1120/995/58 745/800	11 months, 500	70/160/1500	3B		A4-1 / 219 A4-2 / 219
A5 / 47 / 53,29 48 / 09,20	30.09.77.	630/1491/10 1180/1190	4 days, $1.2*10^5$	37/15/130	3B		A5-1 / 219 A5-2 / 219/
A7 / 47 / 50.80 48 / 07,20	17.10.78	1120/1040/73 640/770	49 days, 3	70-100/ 209/520	3B Partially	820/995/1 590/931/1	
A8 / 47 / 55,03 48 / 07,36	17.01.79	1020/1004/65 670/770	26 hours, $4*10^6$	36-76/232/ 520	Dry	219/913/1	
A9 / 47 / 51,42 48 / 09,62	18.12.78	920/630/103 -	16 days, 200	— / — 270	body of water		
A10 / 47 / 51,10 48 / 08,65	24.10.79	975/983/33 680/740	9 months, 5	62/118/370	3B		
A11 / 47 / 52,94 48 / 07,20	14.07.79	1020/983/22 570/680	2 months, 40	36-50/110/ 750	Dry		

3.2. Description of underground nuclear explosions

Cavity A1 – was made in the southern section of the West dome. The 1.1-kiloton charge was detonated on 22.04.1966 at a depth of 161 m.

The area for the experimental explosion is a heavy dome-shaped uplift of the salt array. The thickness of the suprasalt deposits along the well bore of the warfare well is negligible and amounts to 7-8 m. The salt is medium and coarse-crystalline with individual crystals up to 2-3 cm and a distinct stratification.

Layers of salt ranging from 2 to 15 cm fall at an angle of 70° to the north-west and alternate with layers of carbonates and sulphites with thickness ranging from 0.1 to 0.3 cm. Contact of the salt with mantle rocks is cavernous, heavily watered.

The explosion was intended to be confined, the maximal rock hoisting in the explosion epicentre was 2 m. The total soil recovery was observed within about 60 m. Approximately 20 m from the mouth of the warfare well a special research well to a depth of 185 m was drilled and cased, the well head was equipped to measure the pressure through the cracks in the salt; vacuum was formed few minutes after the explosion in the well, an intensive air leak through a hole in the head began which lasted for several hours. The cavity was opened several days after the explosion, first by vertical, then with a deviated horizontal well with sampling of salt molten by the blast. Cavity A1 originally was set as experimental; it is the most studied of all the cavities formed by nuclear explosions in the rock salt.

This made it possible to determine configuration of the cavity, its size, scope, consider the marginal zone of the rocks shattered by the explosion. The cavity by its shape is close to an ellipsoid of revolution with large vertical semiaxis. It had the following dimensions in the first years after the explosion: a maximal height of 37 m and horizontal radius at 12-14 m for a charge planting. The total volume of the cavity is 14.2 thousand m^3. Approximately one-third of this amount is occupied by the collapsed pile of pieces of salt, as well as the molten salt. The cavity relatively quickly was filled with water, which enabled to thoroughly study its configuration with a sonar set. The inner loop of the cavity is surrounded by a zone of crushed halite ranging from 1.5 to 6.5 m. Individual fracture gaps can be traced up to 100 meters or more, down to 30 and to 35-40 m to sides. To obtain dry sealed vessel the adopted depth of the charge proved to be insufficient.

Almost throughout the existence of "GALIT" facility, cavity A1with a complex of adjacent wells were used to work out the methods to study mechanical and radiation effects of explosion, as well as for other studies.

Cavity A2 was created in the northern sector of the West dome. The 27 kt charge was detonated at a depth of 597 m on 01.07.1968. The volume of the cavity was 140,000 m^3. Despite the increase in depth of the charge, at the opening the cavity had already been filled with water to come from the cap rock and overlying rocks. At the moment of the explosion within the contour of the spall craters there were observed water mud spring with removal of fine sand.

During the period from 1975 to 1979, six model experiments were carried out in the cavity with the purpose to prove out the nuclear explosive technologies for obtaining transuranic elements in trace amounts. Charges yields ranged from 0.01 to 0.5 kt, they exploded in the water at a depth of 597 m and could not significantly affect the shape and dimensions of the cavity.

The explosions in the West dome had a pretty sizeable seismic impact on Azgir village, moreover, the dome had a relatively small horizontal area; so, further explosions were transferred to the East dome.

Cavity A3 was created near the Centre of the East dome in the area with the lowest thickness of the backs - 256 m, a 64 kt charge was detonated on 22.12.1971 at a depth of 986 m. In the dry cavity formed with a radius of about 40 m after a few years (29.03.1976) at the same depth a repeated explosion with capacity of 10 kt was carried out in order to study the lowering seismic effect (decoupling). The cavity was intentionally filled approximately with 60,000 m^3 of water, which formed a layer with thickness of 12 m (bottom - 998.7 m, surface - 986.7 m).

Cavity A4 was created in the East dome on 29.07.1976; a 58 kt charge was detonated at a depth of 995 m.

Estimated volume of the cavity is 160,000 m^3. When opening the cavity by drilling out the cement plug an accident occurred and sealing of the boring casing in contact of salt and backs was broken. The cavity was quickly filled with water; top of the warfare well was plugged.

Cavity A5 was created on 30.09.1977 by a 10 kiloton charge detonated at a depth of 1491.5 m. The thickness of suprasalt sediments at site A5 was 325 m. The main purpose of this experiment was to study the stability of the cavities at great depth. The well from the bottom up to the mark ≈11.0 m was filled with sand and cement grouting mortar. The channel within the drain pipe was filled with brine; the top of the pipe had an airtight valve designed for excess pressure up to 300 atm.

Based on the data about the yield of the device the design dimensions of the cavity and its volume were calculated and are as follows:

radius, m	17,8
volume, thous. m^3	23,6
volume of the melt, thous. m^3	4,65
cavity independent volume, thous. m^3	19,04

During 1977-78 cavity was being filled with water in order to test it for internal pressure and observe the flowing at the continuous rate. There were filled 16.5 thous. m^3 with brine with density of 1.17 g/cm^3 by 10.10.1978.

The actual independent volume of the cavity, obtained due to pumping water and air, together with leakage of water and air into a zone of fracturing was 21.0 thous. m^3 (10.10.1978).

The cavity was unsealed after three and a half years after the explosion in March 1981 when drilling well A5 for bulk cross-section. Drilling proceeded almost on the cement stone. According to the sonar data at the time the cavity was shaped in vertical cross section close to elliptical. A hemisphere with radius of 17,5-18,0 m fits the upper part. The independent volume of the cavity was about 15.1 thous. m^3. Comparison of data obtained in determining the volume of the cavity within a year after its formation with the data of sonar recording indicate that over the period since the initial measurement (two and a half years) the volume of the cavity decreased by 25%.

As specified in the program in 1981-83 a pressure testing of the cavity and monitoring of its long-term stability were carried out. The program has not been fully implemented as in

1982 there was a partial closure of the channel connecting the cavity with the surface. The results of these studies are as follows.

The cavity was tested for pressure of about 250 atm., excessive pressure on the mouth during the day, equal to 62 atm., decreased only (approximately) by 2.0 atm. About 120 m^3 of brine was injected into the cavity. Based on this a modulus of deformation of the array surrounding the cavity was determined, which was equal to $0.4 \cdot 10^5$ kg/cm^2. When doing a dry-up job a modulus of the array deformation was also determined which was equal to $0.45 \cdot 10^5$ kg/cm^2. These two measures are close to each other and coincide with the characteristics obtained in the testing of samples, drilled from an array close to cavities A1 and A2.

Based on the analysis of the data obtained the following conclusions can be made:

- the initial volume of the cavity (one year after the explosion) approximately corresponded to the calculated by the Nuckolls formula;
- during the subsequent period the cavity intensively was flowing and its volume after 2.5 years decreased by 25%;
- based on the observations one can assume that at a depth of 1,500 m it is possible to have storage capacities used for the operation while maintaining a constant opposite pressure.

<u>Cavity A7</u> was created on 17.10.1978 in the 1039 m deep well by simultaneous detonation of two charges with the total capacity of 73 kt. In the area of the site an array of salt lies at a depth of 344 m. The well was cased with a pipe with a diameter of 1,120 mm to a depth of 400 m.

Based on data on actual capacities of the charges design dimensions of the cavities and their amounts were calculated:

<u>upper cavity</u>	
radius, m	35.1
volume, thous. m^3	182.0
volume of the melt, thous. m^3	27.0
independent volume, thous. m^3	155.0
<u>lower cavity</u>	
radius, m	23.5
volume, thous. m^3	57.6
volume of the melt, thous. m^3	9.0
independent volume, thous. m^3	48.0
total independent volume of cavities, thous. m^3	203.0.

The volume of the cavity A7, measured by pumping air, was 209 m^3. The roof levels obtained at the opening of the cavity principally coincide with the calculated values obtained with the Nuckolls formula, indicating that there is no significant collapse of the upper cavity roof.

<u>The cavity A8</u> was created on 17.01.1979 by simultaneous explosion of two charges: the upper at a depth of 931.0 m and the lower at a depth of 1,004 m with the total capacity of 65 kt.

During the experiment the well head was depressurised, and there was a slight leakage of gaseous explosion products.

Based on data on actual capacities of the charges the sizes of the cavities were calculated (without taking into account the combined impact of the charges):

<u>upper cavity</u>	
radius, m	21.7
volume, thous. m^3	42.3
volume of the melt, thous. m^3	6.0
independent volume, thous. m^3	36.3
<u>lower cavity</u>	
radius, m	35.4
volume, thous. m^3	186.0
volume of the melt, thous. m^3	28.0
independent volume, thous. m^3	158.0
total independent volume of cavities, thous. m^3	192.3
total independent volume of cavities, measured by air injection, thous. m^3	232.0

The level of the upper cavity, obtained at opening coincides with the calculated one. Level of the melt surface at the bottom of the cavity is 5-6 m below the calculated value, which indicates that there is no melt in the upper part of the cavity. The roof level the lower cavity is significantly higher than estimated one, which is due to the collapse of a large (at least 5-6 m) thick salt. The bottom of the lower cavity is 17-19 m above the calculated value, which confirms the evidence of a roof collapse.

Volume of the broken-down rocks is not less than 8.0 thous. m^3. Volume of the piles is 11.2 thous. m^3. Amounts of the piles were calculated taking into account the loosening of the broken-down rock. The total independent volume of the cavities is estimated at 190.0 thous. m^3.

During the survey the cavity was dry. During the drilling to open the cavity about 2,000 m^3 of water got into the cavity.

<u>Cavity A10</u> was created on 24.10.1979 in the well with a diameter of 975 mm and a depth of 1,025 m by detonation of two charges with a total capacity of 33 kt.

Based on the actual capacity of the charges the design sizes of cavities were specified:

<u>upper cavity</u>	
radius, m	29.5
volume, thous. m^3	108.0
volume of the melt, thous. m^3	15.0
independent volume, thous. m^3	93.0
<u>lower cavity</u>	
radius, m	21.2
volume, thous. m^3	39.6
volume of the melt, thous. m^3	6.0
independent volume, thous. m^3	33.6
total independent volume of cavities, thous. m^3	126.6

Cavity A11 was created on 14.07.1979 by simultaneous detonation of three charges with total capacity of 22 kilotons at depths of 849.3 m, 917 m, 983 m. Well A11 was drilled to a depth of 1003.0 m, the diameter of the well in the uncased part was 985-1,150 mm. In the area of the site an array of salt is at a depth of 280 m, in the backs the well is cased with pipes with a diameter of 1,020 mm to a depth of 400 m.

Based on the actual capacity of the charges here are the design dimensions of the cavities:

upper cavity	
radius, m	26.2
volume, thous. m^3	75.2
volume of the melt, thous. m^3	10.0
independent volume, thous. m^3	65.2
middle cavity	
radius, m	16.1
volume, thous. m^3	18.8
volume of the melt, thous. m^3	2.5
independent volume, thous. m^3	16.3
lower cavity	
radius, m	20.2
volume, thous. m^3	34.4
volume of the melt, thous. m^3	5.0
independent volume, thous. m^3	29.3
total independent volume of 3 cavities, thous. m^3	110.8

Site A9. The most powerful out of single explosions - A9 was held on the southern slope of East dome at a depth of 630 m, i.e. quite sufficient for camouflet, but at the epicentre of the explosion a losing funnel crater with a diameter of about 500 m and a depth of about 30 m was formed, and the mouth of the warfare well is located outside the crater. Thickness of overburden at the epicentre of the explosion is 325 m. The bottom of the crater was filled with water. The main reasons for the cavity collapses happened are insufficient knowledge of geology of southern slope of the of East Salt Dome (cap rock structure, the steepness of rocks, etc.), deviation of warfare well from a vertical position while drilling the toward side edge of the dome, as well as a considerable volume of the formed cavities (the estimated radius is about 50 m) and the size of fracturing zones and deformation of rocks [2].

4. BASIC MECHANISMS FOR POSSIBLE MIGRATION OF RADIONUCLIDES FROM THE UNDERGROUND CAVITIES INTO THE ENVIRONMENT

The UNEs venue at Azgir test site is unique to study migration processes of radionuclides in salt formations. The underground cavities are in fact facilities for radioactive waste disposal - products of the nuclear explosions and can be used as sites for the experimental studies on the results of forced implementation of the geological concept for deep final disposal of radioactive wastes, including long-lived and high-level ones, from the environment. At that fixation of refractory radionuclides (cesium, uranium, plutonium, etc.) in the explosion zone is quite reliable, but their migration - is unlikely, because they are concentrated in a thin spherical shell at the bottom of the original cavity and then covered with the entire thickness of the lentil of melt leaking down due to the melting of its walls. It basically refers to the α-activity, and as for the β-activity, its carriers with T1/2 from 1 to 30 years are more mobile and are found in small quantities outside of the lentil in the areas adjacent to the contour of the cavity.

Radioactive contamination of the array surrounding the cavity A1 was recorded in the near-surface zones of the salt dome Western Azgir at UNEs venue. In the aslope-vertically positioned salt formations of Chapchachi stem certain explosively propagating cracks came to the surface under a thin layer of sandy rocks and loam. The radius of the halo of contamination on the surface was about 300 m around the warfare well.

Based on the observation of the wells near cavity A2 and well A2 itself on the hydrogeological cross-section two regions with different characteristics of brines are singled out:

- from the bottom of the cavity to a point of 300 m - highly mineralized brine (300 g/l) with increased activity (9 mR/h);
- from a depth of 300 m to the mouth of the well - brine (30 g/l) with an activity of 90 mR/h.

Radioactive aureole zone is formed by the destruction of the integrity of the rocks around the explosion cavity and penetration of gaseous and volatile radionuclides through cracks and fracturing areas. Sizes and configuration of the aureole zone depend on the type of salt body (dome, stem, and layer) and on its internal stratification and tectonic structure. In the stratified deposits sub-horizontal discontinuities are intensively growing; through which radioactive melt penetrate the host rocks. The explosion A1 made in the rock salt of West Azgir stock led to sharp opening the primary cracks, until they are released to the surface at distances of up to 220 m from the cavity (cavity radius is 14 m) [4]. Configuration of the aureole zone in the rock salt is asymmetric with respect to the cavity and has a maximal spread in the direction of the earth's surface. The size of this zone is equal to 3-5 radii of the cavity formed [5]. Radioactive aureole zone is an area altered due to the explosion of the rocks where the phenomenon of fractionation is most clearly demonstrated - radiochemical separation of radionuclides associated with the peculiarities of the radioactive decay of chains and chemical behavior of each element [6]. For example, some of the formed krypton-90 and xenon-137 injects through the cracks into the aureole zone and decay there, leaving a long-lived radionuclides strontium 90 and cesium-137 in the mountain massif. The explosion A1 originally caused injection of about 80% of the resulting cesium-137 and about 50% of the resulting strontium-90 into the aureole zone. In the case of filling the explosion cavity with water (sodium chloride brine) the radionuclides redistribute between the aureole zone and the cavity. Redistribution takes place in two stages: first the suprasalt water moving down partially "wash" the cracks, and then, after filling the cavity with a solution, the radioactive brine moves from top downward, and already can add some additional contamination into the cracks. As a result of this double movement of solutions for the explosion cavity A1 the following distribution of strontium and cesium was observed:

Zone, stage	Strontium-90	Cesium-137
Aureole zone	50 %	43 %
Brine in the cavity	3 %	36 %
Remolten salt	47 %	21 %

The study of core samples showed that within the radioactive aureole zone the radionuclides are distributed very unevenly and concentrated, as a rule, on the faces of fissure separating the layers of halite from the clay-carbonate rocks. Additional visual information about the presence of radionuclides in the samples of rock salt of the aureole zone is given by the halite coloration: from blue to dark purple. At the same the areas with the highest concentrations of radionuclides has the densest coloration. Under natural conditions, the blue spotted coloration of the halite crystals is due to the formation of colloidal particles of sodium under the influence of radioactive potassium. The samples taken layer-by-layer from the specimens of the aureole zone (1-2 mm thick saw cut) gave a difference in the concentrations of cesium-137 for a one-two orders of magnitude over distances of 4-5 mm. Its maximal concentrations were observed at certain clay layers at 5-6 m above the cavity roof and amounted to $1{,}2 \cdot 10^4$ Bq/kg. It should be noted that the average concentration of cesium-137 in the remolten salt of the A1 cavity bottom was $1{,}4 \cdot 10^3$ Bq/kg.

Characterizing the migration of UNEs products their natural and geochemical aspects must be taken into account. Since there is no macroscopic motion of matter from the cavity into the surrounding array is due to the fact that the pressure in the cavity is much smaller than lithostatic one, the radionuclides will migrate from the cavity by transfer with the aqueous medium, as well as gas and steam contained in the pores of the array salt, as diffusion coefficients of the substances in the solid phase and solution are many orders of magnitude smaller than the diffusion coefficients in gases.

The natural and man-made distribution system of UNE products include:

1) Radionuclides - fission products that are unevenly distributed in different structural and geochemical zones and different (inherited and newly formed) minerals of explosive origin.

Strontium-90 and cesium-137 available in different zones of the explosion demonstrate much greater mobility, but mainly in the discontinuous fault of the aureole zone. They exist in the form of readily soluble chlorides. Under certain conditions, the two relatively long-lived radionuclides will have migration abilities.

2) Migration channels - open spaces in the mountain rocks and minerals, filled with liquid and gas phases. For the salt-dome Great Azgir structures we may distinguish two types of such channels. The first - stratification and structural boundary between two rocks or minerals and inter-crystal pores and capillaries. The main mechanism for migration of these channels is diffusion. The second - natural porosity of aquifer sandy deposits of the suprasalt thickness [6]

The radionuclides in the medium migrate with water vapor. The mechanism of vapor transport in the pores of the medium depends on the characteristic size (radius) of the pore and distribution function by their sizes. In addition, the transfer coefficient depends on the molecular composition of the vapor, temperature, and for the diffusion transport - on the gas pressure.

Radioactivity transport equation is as follows:

$$\frac{Dn}{Dt} = div(D\nabla n) - \lambda n,$$

n – concentration of radioactive material per unit volume, Ci/m^3;

D – transfer coefficient (diffusion coefficient), m^2/year;

λ - constant of radioactive decay, 1/year.

Thus, the migration rate of the radionuclides in the medium is defined by the transfer coefficient *D*. This coefficient depends on the composition of the transported gas, its temperature, pressure and the pore distribution in a medium by sizes and is associated with such characteristics of the medium as porosity and permeability.

In order to determine *D* it is necessary to know the chemical composition of volatile compounds of the radionuclides, coefficient of their diffusion in the air, and to have experimental data on the permeability of the salt array near the cavity.

The calculation results show that even under assumptions greatly overstating the radioactivity level in the cavity and the rate of radionuclides transfer in the array, the area of radionuclides migration from the cavity is less than half of the cavity radius. Apparently, at comparable distances the radionuclides can penetrate into the array at the time of the explosion forming a cavity during severe deformation of the medium under high pressure generated in the cavity.

At UNEs sites, along with the natural channels of migration, there are discontinuous faults in the mountain rocks of technological origin. This includes the rock salt crushing zones around a cavity, zones of fracturing, spall cracks, etc. We should also consider the possibility of healing the discontinuous faults in the rock salt at relatively shallow depths.

According to the data available, the main channel connecting the cavity or aureole zone with the overlying aquifers is a stem and destroyed annulus space of the main (emplacement) well. The intensity of the water inflow into the cavity is also increased by the spall fractures at the boundaries of the rocks with various compositions, adjacent to the main well [7].

3) Migration medium - aqueous solutions and gas-liquid mixtures that are in the channels of migration. Migration of radionuclides in porous media is controlled by the following mechanisms [7]:

- flow - movement of the nuclide at a speed of groundwater flow;
- diffusion - proliferation of a nuclide within the stream or in a stationary liquid under the influence of the concentration gradient;
- dispersion - distribution of radionuclides due to the difference in motion in porous media;
- sorption - a reversible interaction of the nuclides between mobile and stationary phases (ion exchange, adsorption, filtration), resulting in slower motion with respect to the velocity of water flow;
- loss of mobility - precipitation and co-precipitation of nuclides;
- radioactive decay - a process that determines its final concentration in groundwater in the discharge zone.

4) Geology and chemical environment - rocks, minerals, geochemical zones directly interacting with radionuclides that are in migratory water solutions.

The minerals, such as halite, anhydrite, badly retain the radionuclides, especially in saturated brines. However, the layers of clay minerals in the rock salt massif West Azgir are a significant obstacle for radionuclides to migrate. The regional barriers in the development of the structure Great Azgir are montmorillonite clays and loams of the Neogene sediments (Apsheron stage). The clayey minerals are present in younger deposits of the Khazar and Khvalin stages as well.

The situation at the facility "Galit" under the terms of migration can be characterized as follows:

- lack of retention properties in the rock salt is compensated by low-permeability salt rocks;
- porous sandy rock of the suprasalt deposits are constantly interbedded with clayey material with good barrier properties with respect to the radionuclides.

The most likely migration channels above the cavity will be the cracks of the areole zone and the bores of the technological wells in the rock salt. The first change of physico-chemical conditions occurs in the gypsum-anhydrite rocks with better barrier properties than salts. It is further assumed the existence of channels in the broken cement of the annulus space, within the spall cracks. For the Western and Eastern domes the suprasalt strata has natural barriers - clays that can retain and absorb such migratory radionuclides as strontium-90 and cesium-137. In this case, the higher on the geological section, the more fresh solutions are; the retention capacity of clays therefore increases. The aquifers may also have barrier properties, as here is the dilution of radioactive solutions and in sulphate waters - deposition of strontium.

To reveal the direction of radionuclides possible proliferation, it is necessary to consider the geological and hydrological features of the structure Great Azgir. The Eastern and Western Azgir are separated by a sufficiently large compensating trough Uzhantator. In respect of the hydrogeology the trough is a local artesian basin with spouting of brines from the wells drilled in its central part. In the migration system the trough plays the role of the local pool for moving waters, and impurities they contain (radionuclides). Exactly towards the trough it is possible for fluids to migrate from the cavities of A1, A2 and likely from A3.

Migration, i.e. proliferation of radionuclides, is a complex multicomponent process occurring at the same time with several favourable conditions: presence of migratory component, migration channels, a favourable environment, lack of geochemical barriers, etc. The absence of at least one of these conditions excludes the whole process.

For the condition of "dry" cavity at a known diffusion coefficient of 10^{-18} cm^2/s the migration of strontium-90 or cesium-137 in 500 years will be at a distance of only a few centimetres. The made prediction is confirmed by geochemical studies of the salt formations. In the salts of the Permian Donets Basin, in the layered salt rocks of the Western massif of the Great Azgir no migration between the enclosing rock and the components genetically not related to the salt formation process was found during the long geological age. In the first case – it is interlayer with high concentrations of manganese, titanium, vanadium and copper, in the second – boron-containing tuffites with relicts of volcanic glasses [8].

5. POST-EXPLOSION RADIATION SITUATION IN THE TEST SITE AREA

The status of the test site lands is defined by the decree of the Government of the Republic of Kazakhstan dated November 18, 1998 № 1176, according to which the "Azgir" test site lands were transferred into the reserve lands of Atyrau region. In some part of the "Azgir" test site adjacent to the technological sites, according to the order of Akim of Atyrau Region dated August 25, 1998 № 1659-r, until 2024 there is a prohibition on the drilling, exploration and other underground operations (Figure 2).

From 1966 to 1979 at "Azgir" test site there was conducted testing of technologies to create large cavities in the arrays of rock salt for use as a multi-purpose storage, by applying underground nuclear explosions. 17 underground nuclear explosions of various capacities were carried out at ten technological sites, which created nine underground cavities with the initial total volume of about 1.2 million cubic meters. There are no unexploded nuclear charges currently at "Azgir" test site. Technological sites of the "warfare" boreholes, where underground nuclear explosions were conducted, are now fenced off to prevent access by people, animals and vehicles; radiation hazard signs and prohibiting signs are installed there.

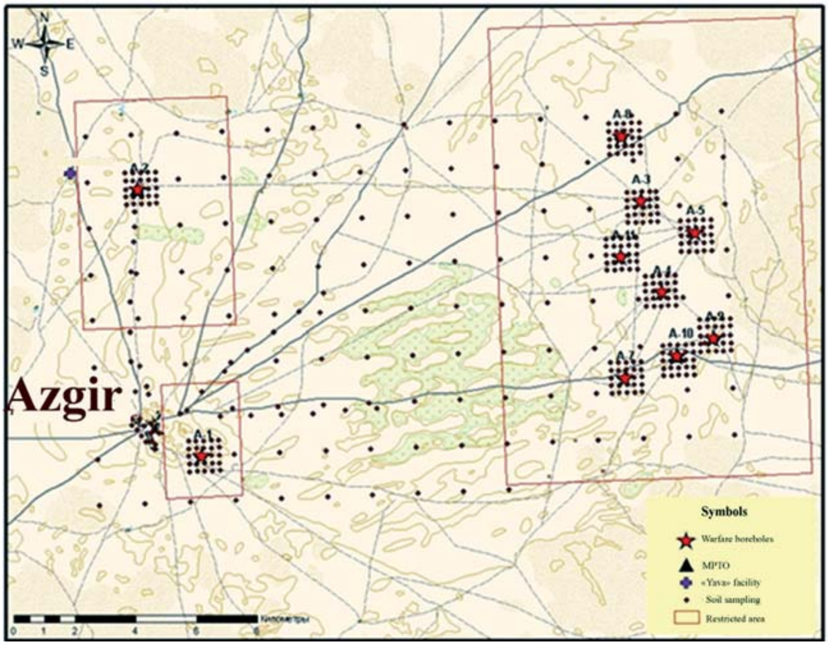

Figure 2. Outline of "Azgir" test site with areas prohibited for drilling, exploration and other activities

All the explosions were designed as a fully confined one, i.e. with no release of radioactivity from explosion to the surface. However, this was not achieved, as evidenced by data from Table 1 about the duration of radioactive emissions from the cavities from a few days to several months and their total activities up to $10^{17}÷10^{18}$ Bq. Some explosions caused efflux of radioactive inert gases (RIG), in these cases the radiation situation at industrial sites was defined by its regime and weather conditions at the surface and boundary layers of the atmosphere. In particular, such situations are explosions in the wells A1, A2 and A8. The explosions in the wells A1 and A8 caused earlier efflux of the RIG (T_0~12 and 60 min, respectively) that was not relevant to the estimates, which then complicated the work of the personnel. In this regard, both cases were classified as emergency radiation situations in accordance with the decision of the Interagency Panel for assessment of radiation and seismic safety of underground nuclear testing. The remaining explosions are characterized as full camouflet explosions: a "gas flame" was caused mainly by short-lived radionuclides of inert gases and at its jet propagation cannot be traced further 7-8 km from the epicentre. In all cases, except for the explosion A1, at a specified distance there were no settlements; during the explosion A1 the gas jet did not pass through the village Azgir. The maximal dose gained by an Azgir resident was 300 mRem at the time of uncontrollable emissions at the explosion at A8 site.

According to [3, 9] at all the gas-aerosol emergences within the sanitary protection zone there were measured dose rates of gamma radiation, surface beta-contamination of soil, flux of beta particles, volumetric activity of radioactive gases and aerosols. After the gases released there were measured the contents of radionuclides in soil and plants. The traces from the gas-aerosol flames were well discernible with portable devices. Particularly, the places where the gas jets "landed" were clearly recorded. The soil contamination area at site A5 is shown in Table 2.

Table 2.

Contamination of soil after the explosion A5

Level of contamination beta-particles/cm^2×min.	20-100	100-300	300-1,000	1,000-3,000	3,000-10,000	> 10,000
Area, thous.m^2	94	35	8.6	2.4	1.0	0.1

Opening the cavities (drilling of cement plugs at development well or drilling access wells), studies of geophysical parameters of the cavities, study of radionuclide migration, extraction of radioactive rocks, sampling of brine, technical operations for different purposes and the negligent operations have resulted in local contamination with activity levels of up to 10^5 mR/h in areas around the development wells at most sites, where soil, drill mud, individual units of equipment and facilities got polluted up to a level of 10^6 decay/cm^2*min for beta radiation, and 10^4 decay/cm^2*min for alpha radiation. The poor decontamination operations to restore the natural characteristics of the soil cover at the sites caused disclosure of local contamination areas, which are sources of radioactive contamination of the environment due to wind and water erosion of the soil surface layer.

In relation with the unfavourable health conditions of the population, there was an attempt to reconstruct the radiation situation on the test site and outside of it at the time of the nuclear explosions, even though the original data (Table 3) were not complete.

Table 3.

Reconstruction of the radiation situation at the test site and its areal

Sites	Azgir		Balkuduk		Distance from the wells, m	
	distance., km	dose, ram	distance., km	dose, ram	dose, 10 ram	dose, 1 ram
A1	1,5	0.140	26	0.002	150	500
A2	8	0.080	26	0.054	900	3100
A5	18	0.002	42	0.001	110	420
A8	17	0.300	41	0.120	750	3000

Many years of the groundwater radioactivity monitoring (Tables 4 and 5) showed that radioactivity level of the underground waters in the vicinity of the well A3 has not changed (or changed very little). This suggests that the inflow of radionuclides into the groundwater in the vicinity of technological sites (excluding technological site A1) occurred simultaneously with underground nuclear explosions, probably as a result of leakage of gaseous precursors of radionuclides cesium-137 and strontium-90 (xenon-137 and krypton- 90). On the other hand, a small change in the concentration of radionuclide Cs-137 in the underground water of the technological site A3 may testify both the isolation of the aquifer structure, and low-velocity of underground water flow in the event that there are redistribution processes (sorption-desorption) of radionuclides cesium-137 between water-bearing rocks and underground water.

In the underground water of the site A5, cesium-137 content was found in the underground water sampled from the observation wells A5-2 located 100 meters from the main technological wells [10, 11]. The specific activity of underground water for cesium-137 was 18 Bq/l as of 1990 which is slightly higher than the intervention level - 11 Bq/l (NRB-99), while it is significantly higher than the global radioactive contamination of surface waters in the ocean - $10^{-4} \div 10^{-3}$ Bq/litre.

Table 4.

Cesium-137 content in groundwater at Azgir test site, Ci/liter (Bq/l)

Site, well	Year of observation		
	1989	1990	1991
A1-1	-	4.4×10^{-9} (161,7)	3.8×10^{-9} (141,5)
A1-2	-	-	3.8×10^{-9} (141,5)
A1-3	-	2.0×10^{-9} (74,7)	5.0×10^{-10} (18,6)
A2-1	1.1×10^{-12} (0.04)	1.1×10^{-12} (0.04)	5.3×10^{-12} (0.19)
A2-2	8.1×10^{-13} (0.03)	6.8×10^{-13} (0.025)	3.7×10^{-12} (0.14)
A4-1	5.6×10^{-12} (0.21)	9.7×10^{-12} (0.36)	2.3×10^{-11} (0.84)
A4-2	3.2×10^{-12} (0.12)	2.1×10^{-12} (0.076)	6.2×10^{-12} (0.23)
A5-1	2.8×10^{-10} (10.2)	1.6×10^{-10} (6,1)	1.9×10^{-10} (7,0)
A5-2	-	4.8×10^{-10} (17,7)	3.2×10^{-10} (12,0)

Table 5.

Cesium-137 content in ground and surface waters of Azgir test sites

Year of observation	A3		A7		A9	
	Bq/l	Ci/l	Bq/l	Ci/l	Bq/l	Ci/l
1981	2.5	6.7×10^{-11}	-	-	1,5	4.0×10^{-11}
1982	2.9	7.8×10^{-11}	-	-	0.9	2.4×10^{-11}
1983	1.9	5.1×10^{-11}	0.14	3.8×10^{-12}	0.5	1.3×10^{-11}
1984	1.7	4.5×10^{-11}	0.11	2.9×10^{-12}	0.42	1.2×10^{-11}
1985	-	-	-	-	0.24	6.6×10^{-10}
1989	1.9	5.1×10^{-11}	-	-	-	-
1990	0.66	1.8×10^{-11}	-	-	-	-
1991	7.2	1.9×10^{-10}	-	-	-	-

As it is known [12], in areas with severe arid climate the plant species formed under these conditions have relatively high radioresistance, especially xerophytes, an environmental group of which includes most of the existing plant here. This also applies to crop plants, particularly cereals, which grow in arid steppes. It is also known [13] that at irradiation with natural UVR, particularly short-wave, there are tangible alterations in living organisms and a mechanism of protection is formed against the radiation damage. In addition, soil salinity is negatively correlated with the content of strontium-90 in plants [14]. All of this suggests that environmental conditions of the research area dot not contribute, as a whole, to the accumulation of radionuclides in the vegetation cover.

6. CURRENT RADIOLOGICAL SITUATION

Since the Institute of Nuclear Physics NNC RK (INP NNC RK) took in 1998 the responsibility over the territories of the former "Azgir" test site to carry out radioecological and radiation monitoring in the period from 1998 to 2003 within the State program "Development of atomic energy in Kazakhstan" and at present within the State "Development of atomic energy in the Republic of Kazakhstan", as well as under the environmental protection programs of the Ministry of Environmental Protection and local authorities of Atyrau oblast, systematic studies of the radiation environment are in progress there, which formed the basis for developing a program for integrated systematic monitoring approved by the Atyrau regional environmental protection agency on October 22, 2001 and the Regulation on the monitoring system approved by the Ministry of Natural Resources and Environmental Protection of Kazakhstan on June 21, 2006. So, Azgir scientific and production radioecological expedition of the INP NNC RK with 11 staff members was established here to carry out operational monitoring of radiation situation at "Azgir" test site and to protect the site.

6.1. Radiation environment at technological sites and surrounding areas

In the territory of the former "Azgir" test site there are 10 technological sites (A1÷A5, A7÷A11), 8 of which are located at a distance of 17-20 km north-east of Azgir village, site A1 - 1.5 km to the east, and site A2 - 8 km to the north (Figure 2).

In 1995, a series of studies was carried out by the National Nuclear Centre of RK and KazHydroMet. Measurements of exposure dose rate of gamma-ray background showed that the activity levels of the gamma-ray background on the sites did not exceed natural levels, and data on the cesium-137 content in soil largely confirm the results of the St. Petersburg expedition. Cesium-137 amounts in soil of the test sites exceed the global reserves in soil (65 milli-Ci/km^2) for Kazakhstan and Central Asia. The contamination in the sites' territory is unevenly distributed, has a spotty nature and varies widely.

Since 1996 the INP NNC RK has conducted regular monitoring of radiation situation in the territory of Azgir test site. The first results of radiometric surveys and measurements of radionuclides density in the soil showed that the exposure dose rate (EDR) at the sites in the main do not exceed natural levels, except for a limited number of individual points, where the EDR values reached up to 400 micro-roentgen/hour (sites A2 and A5). Maximal contamination was registered at the test site A3.

During the last period, the most serious situation has developed at the site in 1997 when there were intensive subsidences of the earth's surface and mass disease of animals; on this occasion the State Commission on Emergency Situations inspected the site. The subsidences were bottle-shaped at a depth of 2 meters in diameter up to 1.5 m. The subsidences, obviously, was the result of karstification due to the intense in that year the flood waters and atmospheric precipitations. This can be attributed to landslides arising as late effects of the UNEs as discontinuity of the environment as a result of dynamic impacts on the suprasalt rocks in the past. The INP NNC RK members, who were part of the commission, carried out a detailed examination of radiation situation, soil sampling and gamma spectrometric analysis and found increased levels of cesium-137 in the surface layer of soil at the sites A2, A5 and A10. Probably, such high concentrations of cesium-137 were due to the release of radionuclides from the trench disposals, as well as the fact that during the restoration by the Russian experts some radioactive spots, unfortunately, were overlooked, and the wind and water erosion exposed them. To solve these and other problems, the INP NNC RK attracted the funds of the International Science and Technology Centre (ISTC). Within the ISTC Project K-152 together with al-Farabi Kazakh National University there were developed a technology framework to reduce wind and water erosion at Azgir test site employing polymeric structure-forming agents.

The maximal level (EDR - 1200 micro-roentgen/hour) and number of spots of radioactive anomalies were detected (as per data of the year 1999) at the A2 site. At the sites A3, A5 and A10 the EDR comprised 790, 400 and 290 micro-roentgen/hour, respectively. The areas of single spots of contamination, where elevated levels of EDR were recorded, ranged from 0.1÷0.2 m^2.

The radiometric survey in 2000 at Azgir test site showed that the highest radiation background was recorded at the sites A2, A3 and A10, where the maximal levels of EDR were 560, 750 and 900 micro-roentgen/hour, respectively. As a result of the works carried out by the INP NNC RK in 2000 to eliminate the radioactive spots with EDR values more than 1,000 micro-roentgen/hour at the Azgir sites, the number of the most radioactive spots decreased.

6.1.1. Soil contamination with radionuclides of artificial origin

In 2005, upon the instructions of the Ministry of Environmental Protection under the State program 003 "Research on the comprehensive survey in the areas of military testing facilities and adjacent areas to determine their ecological condition (Azgir)" the INP NNC RK investigated in detail the radiation conditions in the territories of the estuarine and adjacent areas. The contents of the main dose-forming elements (plutonium, strontium, americium and cesium) in the soils of these territories were investigated. Based on the results obtained, in accordance with the "Criteria for assessing the environmental situation of territories", approved by the Decree of the Government of the Republic of Kazakhstan dated July 31, 2007 № 653 a conclusion was made that the level of contamination at the test site and surrounding areas with artificial radionuclides practically does not exceed background levels and meets the requirements specified in the above document.

This conclusion is fully confirmed by the results of a comprehensive radiological survey performed by the INP NNC RK in 2009 as a part of the program for investigation of the former "Azgir" test site for the ecological status of the groundwater.

Among the environment objects to be investigated were included: soil, surface waters and the main sources of water consumption, vegetation and air (determination of radon). The analytical studies were carried out in accredited laboratories of the Institute of Nuclear Physics using analytical methods that provide quantitative determination of isotopes if their content in the soil is at the level of global fallouts.

Throughout the territory pertaining directly to the test site with an area of 265 sq. km, including all technological sites, an on-ground radiometric survey over the network of 1.5 km x 1.5 km was carried out (Figure 2).

The territories around the technological sites with sizes 1 km x 1 km were studied over a network of 250 m x 250 m. The technological sites of 100 m by 100 m were studied over a grid of 10 m×10 m. The densening of the study network is due to small sizes (0.5÷1 m) of the spots of recurrent radioactive contamination of the soil at the technological sites. The on-ground gamma-survey in the areas was carried out with dosimeter-radiometer DKS 96 with continuous listening to the pulse repetition rate. The connection of the profiles and measurement points was conducted using GPS satellite navigation devices with an accuracy of ±10 meters. The EDR values were registered 1 m from the surface. At the points of research the soils were sampled from a depth of 0-5 cm. The Table 6.1 presents a summary of the gamma-survey.

Table 6.

Summarized data on gamma-survey at the test site (2009)

	Q-ty of measurements	EDR, µSv/h		
		minimal	average	maximal
Test site territory	120	0.05	0.09	0.14
Territory around the sites	250	0.06	0.09	0.25
A1	25	0.07	0.10	0.11
A2	25	0.07	0.08	0.25
A3	25	0.06	0.09	0.13
A4	25	0.06	0.08	0.10
A5	25	0.07	0.08	0.11
A7	25	0.06	0.08	0.10
A8	25	0.06	0.08	0.11
A9	25	0.06	0.9	0.12
A10	25	0.09	0.11	0.13
A11	25	0.06	0.08	0.11

These data indicate that almost everywhere outside of the technological sites in the territory directly related to the test site the intensity of the gamma-ray background is 0.05 - 0.14 µSv/h, which corresponds to the background levels and indicates the absence of contamination at the present time. The recorded value 0.25 µSv/h is abnormal according to the standards.

The results of the analysis of soil samples to determine the artificial radionuclides show:

- average content of the isotope Cesium - 137 is within 20-30 Bq/kg, which is almost background level;
- levels of plutonium-239, 240 do not exceed 1.2 Bq/kg, with a mean value of 0.66 Bq/kg;
- concentration of the isotope americium-241 is less than 2 Bq/kg and largely at the level of detection limit of the used analytical techniques or lower, which does not allow an unambiguous conclusion about the levels of its concentration. However, the studies suggest negligible levels of soil contamination with this radionuclide;
- collection of the data suggests that the level of contamination at the test site and surrounding areas practically does not exceed the level of global fallouts.
- measured values of the specific activity do not exceed the values 2.8 Bq/kg for $^{239+240}Pu$ and for ^{90}Sr (0.1 Bq/kg) in the surface soil layer.

The radiation level at the technological sites and surrounding areas does not exceed the established sanitary standards. However, due to the recurrent local spots of the soils with elevated radioactivity within the technological sites, it is necessary to continue ongoing monitoring of soil contamination at the test site.

Here are the average values for ^{137}Cs, calculated for all the objects studied:

Study area	^{137}Cs average concentration, Bq/kg
Area adjacent to Azgir test site (R-20 km)	26.1
Wellhead area A1 (1*1 km)	21.2
Wellhead area A2 (1*1 km)	24.1
Wellhead area A3 (1*1 km)	29.5
Wellhead area A4 (1*1 km)	26.6
Wellhead area A5 (1*1 km)	26.3
Wellhead area A7 (1*1 km)	24.0
Wellhead area A8 (1*1 km)	25.8
Wellhead area A9 (1*1 km)	27.3
Wellhead area A10 (1*1 km)	39.1
Wellhead area A11 (1*1 km)	29.4
Spot 1 at site A2	5290 ± 120
Spot 2 at site A2	1540 ± 80

Spots of radioactive contamination (SRC)

As noted above, the contamination at the test site is recorded only within the range of technological sites, unevenly distributed and has a spotty nature. The following are the characteristics of the contamination at some sites.

Site A1. In 2000, within the site near the "warfare" borehole (Figure 3) there were registered spots of soil contamination with the values of EDR up to 700 mR/h (Figure 4), and data on the content of cesium-137 in soil far exceeded the value of global reserve in the soil for Kazakhstan and Central Asia - 65 mCi/km^2.

Figure 3. "Warfare" borehole A1

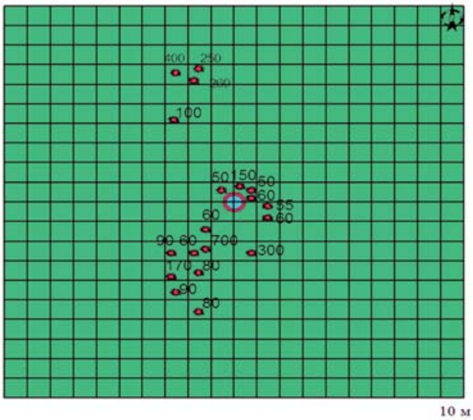

Figure 4. Layout of contamination spots at A1 site (year of 2000)

The reclamation operations carried out in 2001 in the surface storage at A2 site resulted in remediation of 180 kg of radioactive soil. According to the radiological examination (INP NNC RK, 2005) at the present time the radiation situation is due to natural background. The EDR values did not exceed 0.13 µSv/h (Figure 5). In the territory of the site there is a station for monitoring of the soil radionuclide composition. Due to the geology around the site, there there are accidental karst failures in the form of craters with a depth of 1 m. In order to limit access to the site a square-shaped fence with a side length of 45 m was installed.

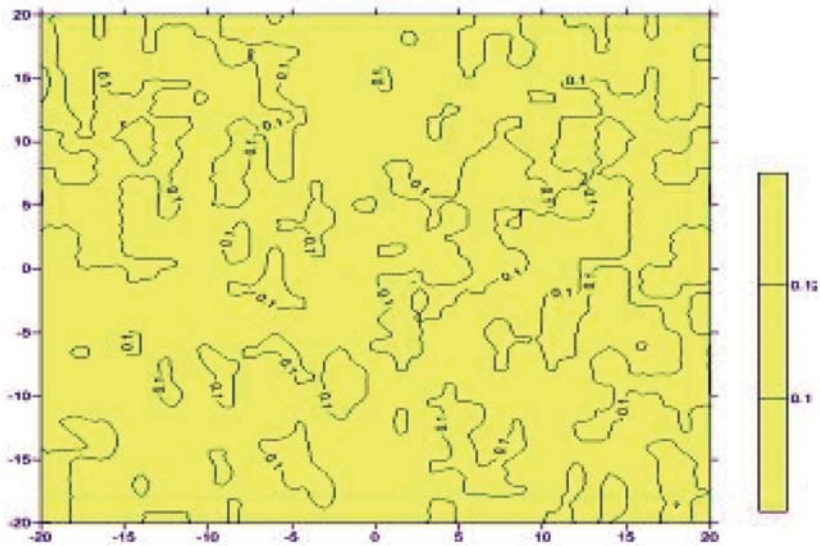

Figure 5. Cartogram of EDR (µSv/h) at the site A1 (2005)

Site A2 (Figure 6) was characterized as the most contaminated one among the technological sites of Azgir test site, both by quantity of radioactive areas and the values of EDR. Before the decontamination of the polluted areas in 2001 at the site there were recorded the EDR values up to 400 mR/h (Figure 7), and after the decontamination their maximal EDR was recorded at 95 mR/h. The reclaiming in the surface storage at the site A2 resulted in decontamination of 2,040 kg of radioactive soil.

The radiological surveys in 2005 (the INP NNC RK) at the site recorded recurrent local spots of radioactive contamination of the soil (Figure 8). Based on the results of the survey the site area was decontaminated again, which resulted in EDR value at the site reduced below 30 µSv/h.

In order to limit access to the site, an inside fence in a circle shape with a diameter of 80 m and a square-shaped outer fence with sides of 120 m in length were installed. In the territory of the site there is a station for monitoring of the soil radionuclide composition.

Figure 6. Technological site A2

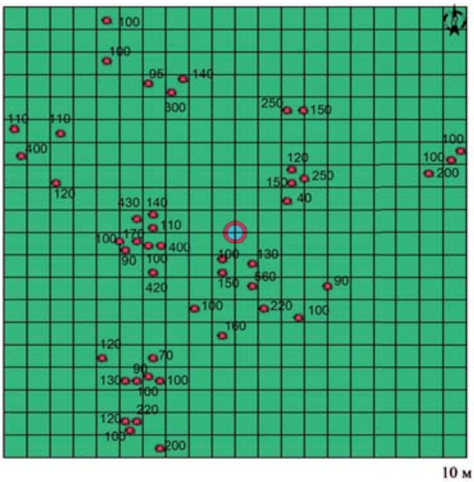

Figure 7. Layout of contamination spots at the A2 site (year of 2000)

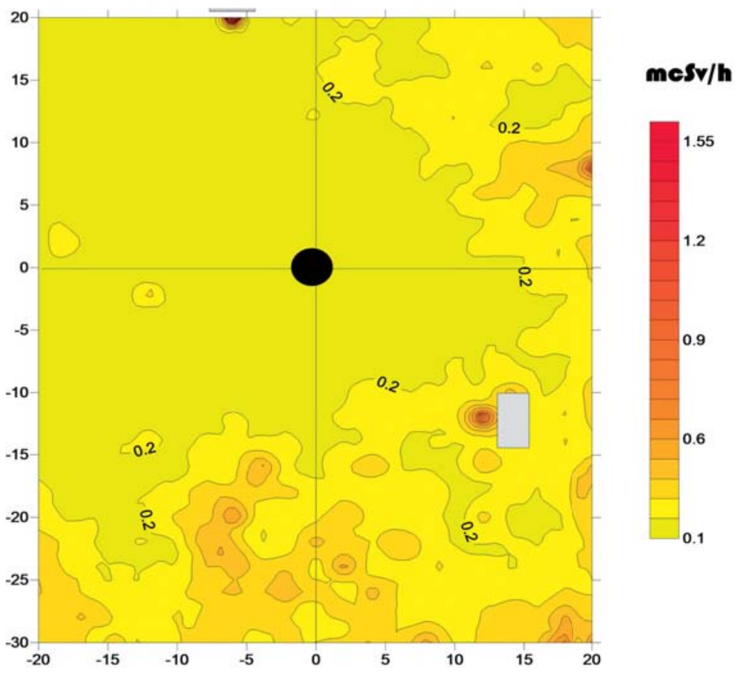

Figure 8. Cartogram of EDR (μSv/h) at the site A2 (year of 2005)

Site A3 (Figure 9). Radiation situation and radionuclide contamination were characterized as a fairly moderate. Prior to remediation at the site in 2001, the values of DER were recorded up to 700 mR/h (Figure 10); following the completion the EDR values were recorded in the range from 25 to 40 mR/h. 180 kg of radioactive soil were reclaimed from the contaminated spots into a repository at the site A10. Due to the emergence of recurrent spots of radioactive contamination of soils found during the radioecological surveys carried by the INP NNC RK in 2005 (Figure 11), the site territory was subjected to re-reclamation. On the site there is a station for monitoring of the soil radionuclide composition and a fence installed in the form of a circle with a diameter of 40 m.

Figure 9. Technological site A3

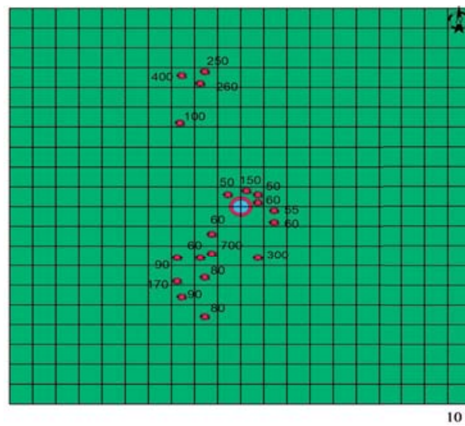

Figure 10. Layout of contamination spots at A3 (year of 2000)

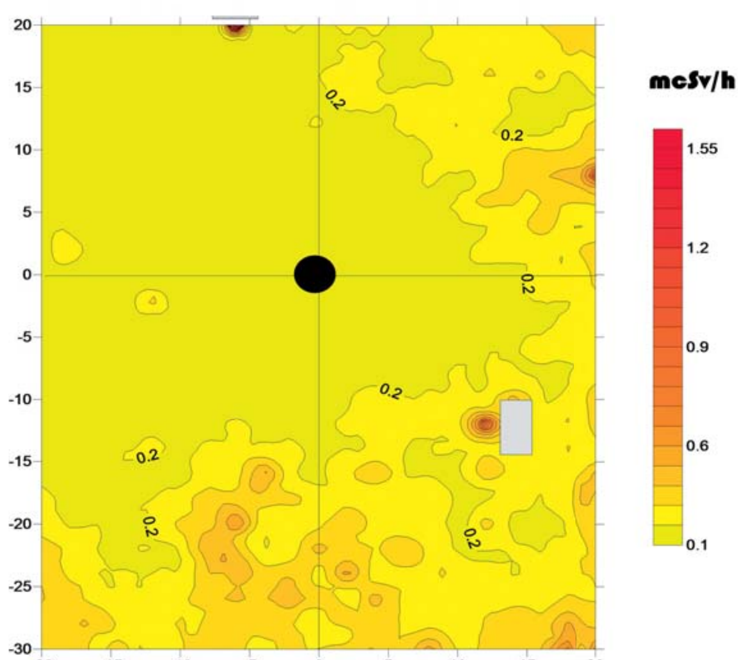

Figure 11. Cartogram of EDR (μSv/h) at the site A3 (year of 2005)

Site A4 (Figure 12). In response to an incident that occurred at the opening of the cavity, no researches at the site were carried out. The radiation situation is normal with natural regional background (Figure 13). A single spot of contaminated soil was deactivated in 2007. At the site there is a station for monitoring of the radionuclide composition of soil and a fence installed in the form of a circle with a diameter of 40 m.

Figure 12. Technological site A4

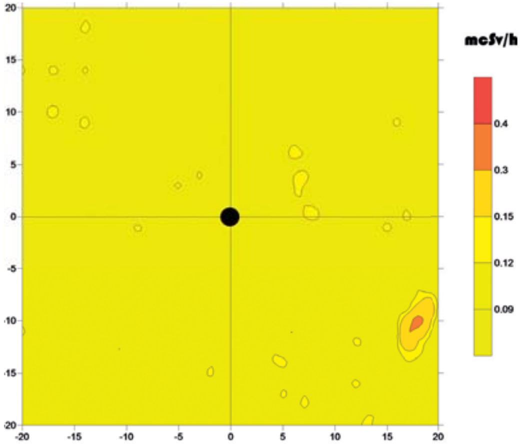

Figure 13. Layout of contamination spots at A4 (year of 2000)

Site A5 (Figure 14) just like the site A3, this one was characterized with respect to radioactive contamination as having fairly moderate parameters. Prior to the clean-up operations in 2001, the radiation situation at the site was as follows: the EDR values were in the range from 40 up to 300 mR/h (Figure 15). After the clean-up operations the EDR values were observed from 12 to 30 mR/h. 360 kg of radioactive soil were gathered and transported to the repository from the site in 2001 (A10). Due to the emergence of recurrent spots of radioactive contamination of soils revealed during the radioecological surveys carried out by the INP NNC RK in 2005 (Figure 16), the site was subjected to re-reclamation. At the site there is a station for monitoring of the soil radionuclide composition. In order to limit access to the site, an inside fence in a circle shape with a diameter of 50 m and an square-shaped outer fence with sides of 120 m in length were installed.

Site A7 (Figure 17) Prior to the reclamation activities in 2001, the EDR values were in the range from 20 to 60 mR/h, and after their completion there is a normal situation at the site; the background radiation is in the range of natural values (Figure 18). 60 kg of soil from one local spot was disposed into the repository in 2001 (A10). At the site there is a station for monitoring of the soil radionuclide composition and fencing installed in the form of a circle with a diameter of 40 m.

Figure 14. Technological site A5

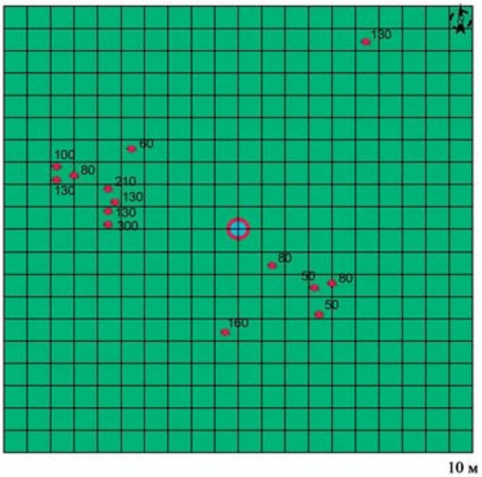

Figure 15. Layout of contamination spots at A5 (year of 2000)

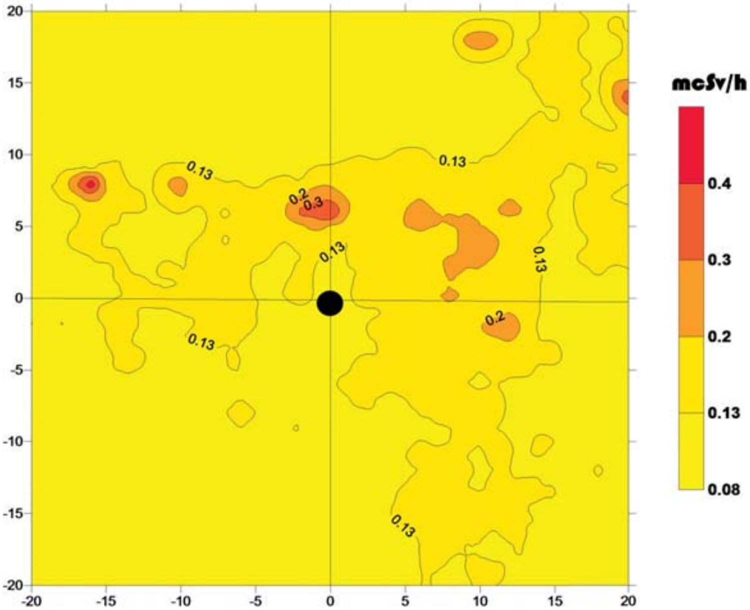

Figure 16. Cartogram of EDR (μSv/h) at site A5 (year of 2005)

Figure 17. Technological site A5

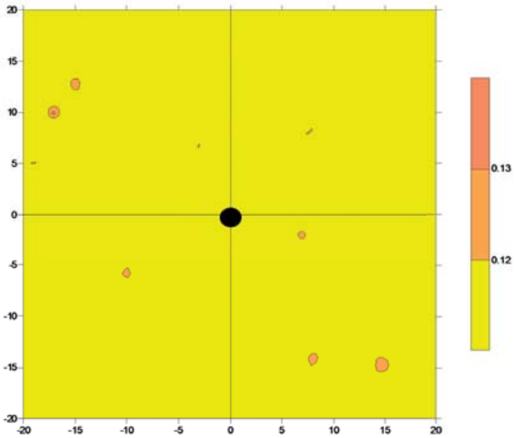

Figure 18. Layout of contamination spots at A5 (year of 2000)

Figure 19. Technological site A8

Figure 20. Technological site A11

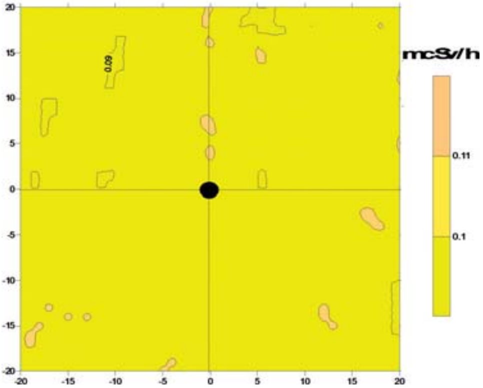

Figure 21. Cartogram of EDR (μSv/h) at A8 site (year of 2005)

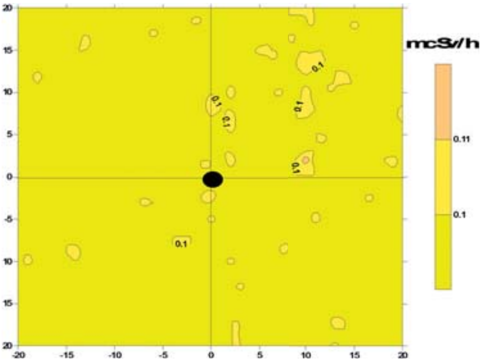

Figure 22. Cartogram of EDR (μSv/h) at A11 site (year of 2005)

Sites A8 and A11 (Figure 19 and Figure 20) - no radiological anomalies. Figures 21 and 22 show the distribution of EDR over the territories of the sites. Each site has one station for monitoring of the soil radionuclide composition and fencing installed in the form of a circle with a diameter of 40 m. No remediation activities were carried out at the site.

Site A9 is located on the southern slope of East salt dome. A feature of the site is the presence of a subsidence crater with a diameter of about 500 m and a depth of about 30 m, and the mouth of the "warfare" borehole is located outside the crater contour (Figure 23). Figure 24 shows the crater filled with ground water. Around the formed lake, there are widespread sinkholes and collapses. According to the radiation survey and the results of continuous monitoring, the site area is characterized by the values of EDR at the level of natural gamma-ray background (Figure 25). Despite the fact that the determination of artificial radionuclides used a sensitive technique with detection limit well below the maximal permissible level, the attempts to detect these radionuclides in the waters of the formed lake failed. The site has a station for monitoring of the radionuclide composition of soil and water.

Figure 23. Technological site A9

Figure 24. Subsidence crater at the site A9

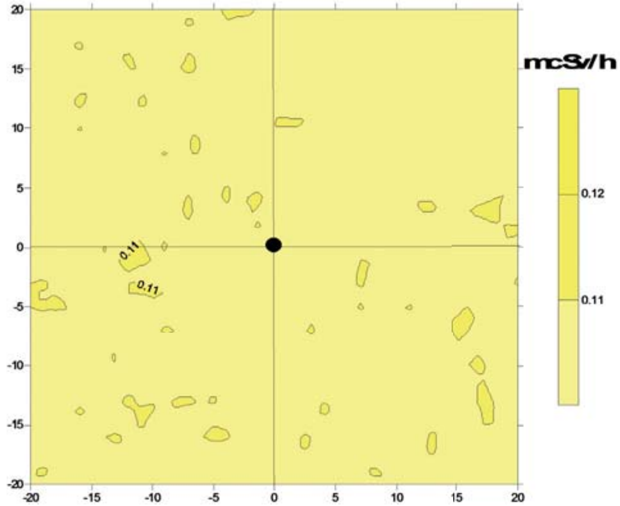

Figure 25. Cartogram of EDR (μSv/h) at the site A9 (year of 2005)

Site A10 (Figure 26). The radiation situation at the site was described as severe because of the large number of areas with radioactive contamination and high EDR. In 2001 the contaminated areas of the site with the highest values of EDR were remediated. Prior to the liquidation of the of contaminated areas, the DER values in 2000 ranged from 80 to 800 mR/h at 63 contaminated spots, and after - in the range from 40 to 70 mR/h (Table 7). 420 kg of radioactive soil was disposed and placed on-site in a repository in 2001.

Figure 26. Technological site A10

The major works on reclamation were conducted in 2007 (Table 8) and, basically, were aimed at dispose of radioactive metal scrap, placed for temporary storing within an outer enclosure area. About 100 units of machinery, equipment and materials non-serviceable for further use had been stored here. An area occupied for storing scrap metal was about 40 000 sq. km. However, only 4 facilities were contaminated:

1. The platform at the gate - 0.4 - 0.7 μSv/h;
2. Crawler track -0.62 μSv/h;
3. Bunker - 0.52 μSv/h;
4. Pump - a distance of 1 m - 0.38 μSv/h, inside - 9 μSv/h.

According to the field gamma-spectrometry, all the objects were contaminated with cesium-137. The soil under the platform, crawler track and the pump was contaminated.

Currently, according to the radiological examination (the INP NNC RK, 2009), the reclamation works at the site resulted in normalization of the radiation situation. There is a station at the site for monitoring of the soil radionuclide composition and fencing installed in the form of a quadrangle (130m x 170m).

Table 7.

Results of gamma-survey of contaminated spots at the site A10 (2001)

Measurement point #	EDR, mR/h before remediation	EDR, mR/h after remediation	Measurement point #	EDR, mR/h before remediation	EDR, mR/h after remediation
A2	60	20	Б103-1	150	40
A16	100	25	Б103-2	130	35

Measurement point #	EDR, mR/h before remediation	EDR, mR/h after remediation	Measurement point #	EDR, mR/h before remediation	EDR, mR/h after remediation
А43-1	270	35	Б117-1	200	40
А43-2	280	25	Б117-2	170	30
А51	90	20	Б117-3	80	52
А54	110	25	Б122	150	69
А62	80	20	Б124-1	150	35
Б53-1	170	30	Б124-2	90	39
Б53-2	90	35	Б124-3	150	35
Б64	190	30	Б124-4	90	25
Б70-1	100	35	Б125-1	120	30
Б70-2	110	30	Б125-2	800	42
Б72-1	90	36	Б126-1	100	32
Б72-2	80	30	Б126-2	110	30
Б80-1	160	30	Г1	60	32
Б80-2	400	30	Г2	60	30
Б87	80	30	Г11	100	32
Б90	130	40	Г21-1	110	38
Б91	110	30	Г21-2	80	36
Б102-1	90	30	Г42	80	30
Б102-2	100	37	Г52	40	30

Table 8.

Results of gamma-survey of contaminated spots at the site A10 (2007 г.)

Sector, square	EDR, µSv/h before remediation		EDR, µSv/h after remediation		Sector, square	EDR, µSv/h before remediation		EDR, µSv/h after remediation	
	H=3 cm	H=100 cm	H=3 cm	H=100 cm		H=3 cm	H=100 cm	H=3 cm	H=100 cm
А2	0.5	0.3	0.35	0.25	Б117	1.6	0.7	0.39	0.30
А16	0.6	0.3	0.30	0.20	Б124-1	0.7	0.4	0.30	0.28
А43	1.2	0.6	0.30	0.20	Б124-2	0.5	0.4	0.25	0.20
А52-62	0.7	0.4	0.38	0.32	Б125	1.1	0.3	0.35	0.30
А54	1.2	0.6	0.38	0.35	Б126	0.7	0.4	0.25	0.20
Б61-1	1.1	0.7	0.25	0.20	В1	0.4	0.3	0.25	0.20
Б61-2	0.7	0.4	0.20	0.15	В11	0.5	0.3	0.20	015
Б52	0.9	0.4	0.30	0.25	В21	0.7	0.4	0.30	0.25
Б53	0.8	0.4	0.30	0.25	В22-1	0.4	0.3	0.20	0.15
Б72	0.6	0.4	0.38	0.30	В22-2	0.6	0.3	0.25	0.20
Б72-82	1.2	0.8	0.20	0.15	В32	0.6	0.4	0.25	0.20
Б86	0.5	0.3	0.20	0.15	В41	0.5	0.4	0.20	0.15
Б87	0.4	0.3	0.15	0.12	В42	0.8	0.6	0.30	0.25

Sector, square	EDR, μSv/h before remediation		EDR, μSv/h after remediation		Sector, square	EDR, μSv/h before remediation		EDR, μSv/h after remediation	
	H=3 cm	H=100 cm	H=3 cm	H=100 cm		H=3 cm	H=100 cm	H=3 cm	H=100 cm
Б88	0.7	0.3	0.25	0.20	В53	0.4	0.3	0.20	0.15
Б90	0.5	0.3	0.20	0.15	Г27	0.6	0.3	0.30	0.25
Б91	1.1	0.6	0.35	0.30	Г28-1	1.1	0.5	0.30	0.25
Б102	0.8	0.4	0.30	0.25	Г28-2	0.6	0.3	0.35	0.30
Б103	1.2	0.4	0.36	0.33	Г49	1.2	0.5	0.35	0.30
Б112-113-122-123	2.1	1.0	0.30	0.25	Г50	0.8	0.4	0.25	0.20
Б113	0.5	0.3	0.20	0.15	Г69	1.8	0.5	0.35	0.30

6.1.2. Contamination of soil with heavy metals

Along with the study of artificial radioactive contamination, the INP NNC RK has been studying macro-and trace-element composition of the environment for a long time. According to the results of studies using high-precision methods of analysis of the presence in soils of 24 elements, no contents of the heavy metals above the permissible levels were recorded.

6.2. Radioecological situation in the nearby settlements

In 2005 and 2009 a comprehensive assessment of environmental quality in three locations: Azgir, Balkuduk and Suyunduk, that is, the settlements that are in the area of maximal potential impact from the former "Azgir" test site. The assessment was conducted on the following parameters: level of soil contamination with artificial radionuclides, levels of artificial radionuclides in the air, quality of surface and drinking waters on the parameters: micro-and macro elemental composition, radionuclide content (including tritium).

In the residential areas 187 points were measured for gamma-ray background. In Azgir village – 29 measurements outdoors, 4 – on virgin lands and 25 – in homes, in Balkuduk village – 34 measurements outdoors, 5 – on virgin lands and 25 – in homes, in Suyunduk village – 35 measurements outdoors, 5 – on virgin lands and 25 – in homes. Samples were taken of such environmental objects as: soil samples in Azgir village – 23 pcs., in Balkuduk – 31 pcs., in Suyunduk – 31pcs.; 12 pieces of vegetation samples – three samples from each village and water samples from sources of drinking and household purposes (water wells) in quantities of 10 pieces. The registers of the samples are given in the Annex in Tables A1, A2 and A5. In residential and business premises 68 measurement of the equivalent volumetric activity of radon (EEVA) were carried out. The radon survey was carried out with radonmeter "Ramon Radon-01" based on the standard method. The results of the surveys in the settlements are presented in Tables 9-11 and Figure 27.

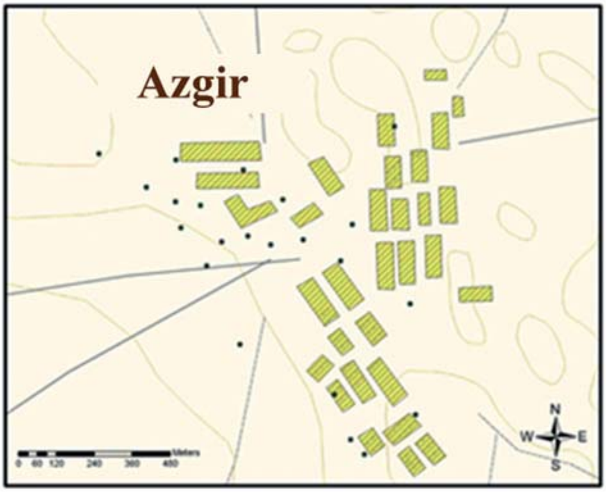

Figure 27. Cartogram of DER measurement and soil sampling points in Azgir village

The gamma background level (Table 9) in the surveyed villages corresponds to the values of natural background for the region. As it can be seen from Table 10, the values of EEVA are on average 65 – 122 Bq/m^3. Single values exceeding 200 Bq/m^3 were recorded, which is associated with poor ventilation in the facilities.

A selective individual dosimetry for the population (7 people) was carried out. The staff of Azgir research and production radio-ecological expedition was measured as the most critical part of the population (Table 11).

Table 9.

Results of gamma-survey in villages

	Q-ty of measurements	EDR, µSv/h		
		minimal	Average	maximal
Azgir village	33	0.05	0.07	0.11
Balkuduk village	37	0.05	0.07	0.09
Suyunduk village	40	0.05	0.08	0.1

Table 10.

Measurements of radon equivalent equilibrium volumetric activity

	Q-ty of measurements	EEVA$_{Ra}$, Bq/m^3		
		minimal	Average	maximal
Azgir village	24	1,0	65	249
Balkuduk village	23	10	76	221
Suyunduk village	21	28	122	233

Table 11.

Individual dosimetry of Azgir research and production expedition staff for the second quarter of 2009

##	Name	Effective dose, per quarter, mSv
1	Gubashov R. K.	0.089
2	Gubashov H. G.	0.125
3	Zhumakulov N. B.	0.097
4	Imangaliev A. K.	0.063
5	Kaliev A. K.	0.099
6	Salikhov S. G.	0.089
7	Uteshev A.	0.102

The determined specific contents of ^{137}Cs, ^{241}Am, $^{239+240}Pu$ and ^{90}Sr in the surface soil of the settlements Azgir, Balkuduk and Suyunduk allow to state that the impact of Azgir test site on soil contamination in the surveyed villages is insignificant. Comparison of ^{137}Cs average concentrations in the soil of these settlements with the level of global fallout is shown in Table 12.

Table 12.

Comparison of average concentrations of ^{137}Cs in the soil of the settlements with the level of global fallouts

Background area (Ganyushkino village)	4.6 Bq/kg
Balkuduk village	7.6 Bq/kg
Azgir village	9.0 Bq/kg
The level of global fallout (for Northern Hemisphere)	10-50 Bq/kg

6.3. Ecological conditions of underground waters

To date, the information on the artificial radionuclides in groundwater at the former "Azgir" test site is insufficient. So far it is mainly based on the studies of contamination with artificial radionuclides in underground waters during the exploitation by the Russian specialists and the monitoring data on the radionuclide composition of the first aquifer at "Azgir" test site and surrounding areas, carried out by the INP NNC RK.

6.3.1. Contamination of groundwater with radionuclides of artificial origin

The Khlopin Radium Institute (St. Petersburg) noted at the sites A1, A2, A3, A5 radionuclide contamination of the underground waters of the lower aquifers not used for water supply. Radioactive contamination of the array surrounding the cavity A1 was detected in the surface zones of the salt dome West Azgir, also revealed the radioactivity in the groundwater in the well A3. In all cases, the concentrations of artificial radionuclides in the waters are far below the maximal allowable concentrations for drinking water. Recent measurements of radionuclide contents in groundwater of the test site grounds were carried out by the Russian specialists in 1991.

The INP NNC RK in 2009 after the restoration of water wells studied the radionuclides composition of the formation waters of the first aquifer at sites A 1 and A 2. Registered with high-precision analytical methods concentrations of artificial radionuclides were 10-100 times lower than the maximal permissible levels.

The researches have not detected artificial radionuclides in the water from draw wells in the adjacent villages. Additionally, content of tritium was investigated in the water (this isotope is a heavy isotope of hydrogen accumulated in the process of nuclear explosions and it has extremely-high mobility). The investigations established that the absence of tritium in these waters allows concluding that there is no impact of Azgir test site on the water sources quality; however, we cannot exclude the effect in the future. Monitoring of the groundwater should be continued, so if the geological situation in the region changes as a result of seismic activity or unauthorized technological activity there is a risk of radioactive brine inflow from the cavities into the overlying horizons.

6.3.2. Indicators of groundwater quality related to natural factors

During a comprehensive survey of Azgir test site and adjacent areas to determine their ecological status there were investigated waters out of the draw wells in Azgir and Balkuduk villages and from an open body of water at the site A9. Figure 28 shows the results of monitoring the elemental composition according to the 2010 and 2011. These water-wells are the main sources of water supply in the area. In all samples, sodium content exceeds allowable hygienic standards; in individual samples it is exceeding the established sanitary standards for a number of indicators such as total mineralization, contents of chloride ion, magnesium and manganese. Based on the integral performance (total index of hazard) one can make an unambiguous conclusion about the unsuitability of the investigated surface waters and water sources for drinking purposes.

As follows from the histograms shown in Figure 28, concentrations of barium, strontium, and manganese is well above the limit values of MAC for drinking water. In general, trace element composition of groundwater in these wells and water-wells compared to monitoring data from 2010 has not undergone significant changes and the recorded differences are due to seasonal factors.

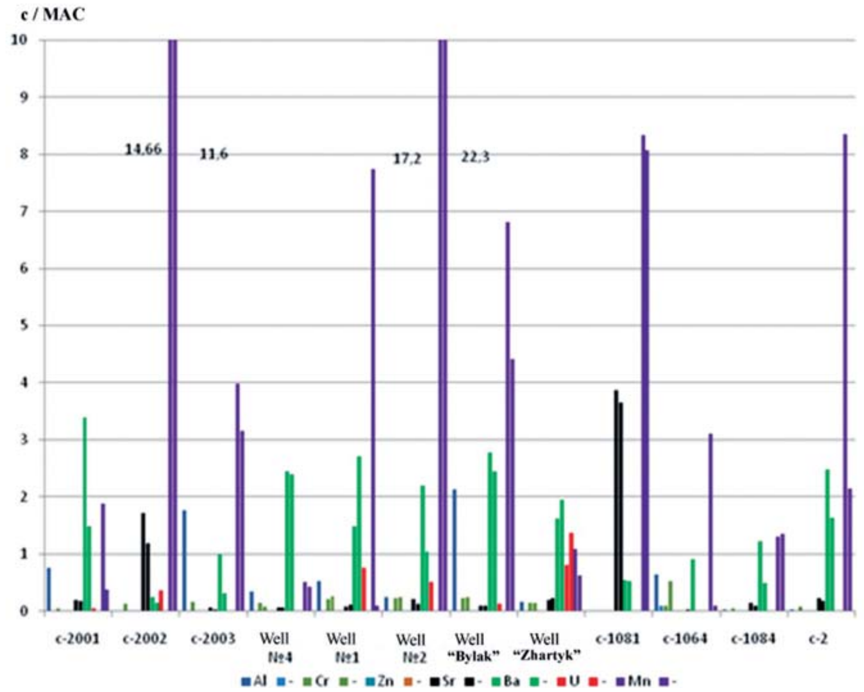

Figure 28. Comparison of microelement concentrations with MAC for drinking water

CONCLUSION

- At present the radiological situation at the technological sites of Azgir test site and surrounding areas remains within the sanitary limits.
- Continuous radioecological monitoring at Azgir test site is to be performed because of the risk of recurrent local spots of soil with elevated radioactivity within the technological sites and migration of radionuclides with groundwaters.
- Major adverse environmental factor in the villages Azgir and Balkuduk is natural quality of the drinking water.

7. CALCULATION OF EFFECTIVE DOSES OF IONIZING RADIATION FOR POPULATION IN VICINITY OF THE TEST SITE

The main task of environmental radiation monitoring is to estimate the equivalent dose from all sources, and much of the radiation monitoring program is associated with the calculation of equivalent doses and comparing them with established state dose limits.

The calculation of the effective dose was performed according to the method developed by the INP NNC RK № 34-01-22/1201 dated 29.12.1999, consistent with the Republican SES RK. Dose coefficients were used from the NRB-99 (Radiation Safety Standards). Also of interest is assessing the effects of radiation as s.p. 2.7 and 2.8 of the NRB-99, i.e. the risk of fatal stochastic effects from exposure to ionizing radiation (radiation risk) and the probability of loss for the lifetime of an individual from Azgir village. Calculation results of the radiological consequences are presented in Table 13.

Table 13.

Assessment of effective dose

Parameters	Unit of measure	Value
effective dose	Sv/year	$1.9 \cdot 10^{-3}$
including from artificial radionuclides		$2.2 \cdot 10^{-5}$
radiation risk	fatality /year	$1.4 \cdot 10^{-4}$
including from artificial radionuclides		$1.6 \cdot 10^{-6}$
probable loss of life time in 60 years		41 days
including from artificial radionuclides		10.8 hour

- It should be noted that the results of the calculations are somewhat too high due to the use of dose coefficients for the most critical groups and for the most toxic chemical forms of compounds with radionuclides.
- The doses of external radiation from artificial radionuclides cesium and strontium are also overstated because the migration processes (horizontal and vertical) were not taken into account.

8. WORKS ON NORMALIZATION OF THE RADIOLOGICAL SITUATION

In accordance with Article 143 of the Kazakhstan Land Code, the lands where nuclear weapons tests were performed may be granted by the Government of the Republic of Kazakhstan to the property or land tenure only after completion of all measures on elimination of nuclear testing consequences and comprehensive environmental survey. In pursuance of this document based on the results of monitoring the INP NNC in 2005 carried out an inventory of radioactively contaminated spots of soil at the test site and scrap metal at a temporary storage location.

Based on the research results, procedure rules to eliminate areas of radioactive contamination at technological sites of the "Azgir" test site were developed and approved. In accordance with the developed rules, certain operations in 2001 and 2007 were carried out to eliminate the most dangerous spots of radioactive contamination at the sites A1, A2, A3, A4, A5, A10, which may pose a potential danger to the public, and dolines of the ground at the sites A1 and A9.

During these works we took into account that the contamination is represented by the contaminated soil (average specific activity of the main dose-forming radionuclides ^{137}Cs was 2687 Bq/kg) and scrap metal, not belonging to the category of radioactive waste. The reason is non-excess of normative values of the actual specific activity of the contaminated materials. The elimination of spots of radioactive contamination (SRC) was carried out by sampling of contaminated soil to the desired depth (up to 30 cm) without the use of mechanized equipment. Transportation to a burial ground was made in compliance with the rules for the transport of radioactive waste. In view of the small size of SRC, no special measures to restore the territory were required (except for covering the treated areas with clean soil).

When disposing the contaminated scrap metal, we faced a need to preliminary separate contaminated scrap metal from the main non-radioactive bulk (Figure 29).

Large-and massive non-transportable radioactive fragments were subjected to cutting into pieces for optimal transportation and laying in near-surface trench disposal.

To dispose the radioactive soil from the areas located on the western and eastern domes, there were prepared subsurface repository facilities for materials of limited use in the territory of the sites A2 and A10. The rocks in these areas are dark gray thick marlaceous viscous clays with interlayers of loam and fine sand. Depth of the showing of the first, from the surface, aquifer at the site A2 is 18 m, and at site A10 – 8 m. In 2007 9,150 kg of soil and 1,900 kg of metal fragments were disposed in near-surface burials (Figure 30).

Figure 29. Fragmentation of contaminated scrap metal

Figure 30. Disposing of radioactive scrap metal and soil in MPTO-10

Upon the reclamation works, an assessment of their efficiency was carried out, which showed that the radiation situation at the test site does not exceed the standards for soils of the relatively safe territories based on the radioactive contamination criterion set by "The criteria for assessing environmental situation of territories" approved by the Decree of the Government of the Republic of Kazakhstan dated July 31, 2007 № 653. According to the results of studies, a database was created in 2008 that is launched in the INP NNC RK and at Akimat of Atyrau oblast.

To ensure reliable restricted access regime in the sanitary protection zones of the technological sites there was installed a fence 30 m and more from a reference stake of the "warfare" borehole.

The fences are made of metal racks with a diameter of 80 mm, height of 2,200 mm (fence height above the ground is 1,500 mm), with the distance between the racks – 3,000 mm. On the racks, three rows of 5 mm wire, a row of reinforcement rods with diameter of 12-14 mm and two rows of barbed wire were installed. In the fence there is a 5 m wide gate (Figure 31).

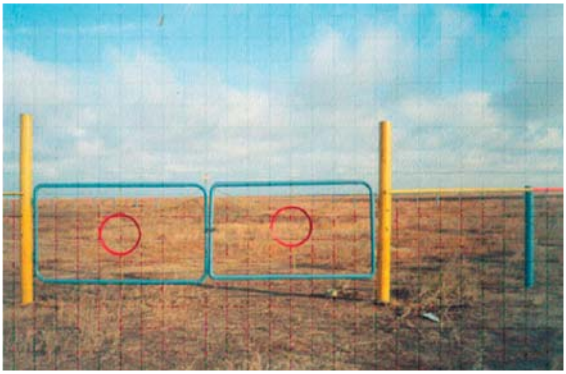

Figure 31. Fencing and gates

During 2009-2010 the works were carried out under the program "Research of the "Azgir" test site impact on the ecological status of groundwater". A technical base was created for monitoring the radionuclide composition of groundwater from 10 monitoring water wells at the former "Azgir" test site and 5 draw wells in the surrounding settlements. The technical base enables to study the nature of the migration processes in groundwater levels to a depth of 20 m.

Once the works are completed, a conclusion will be made in 2011 about the state of groundwater and its prospects to be used for commercial purposes.

REFERENCES

1. Classification and diagnostics of soils of the USSR. - Moscow: 'Kolos', 1977. [in Russian]
   Классификация и диагностика почв СССР. - М.: "Колос", 1977.
2. E. Z. Akhmetov. Azgir test site. Preprint 1-96 the INP NNC / E.Z. Akhmetov [And others]. - Almaty: Institute of Nuclear Physics NNC RK, 1996. [in Russian]
   Ахметов Е.З. Полигон Азгир. Препринт 1-96 ИЯФ НЯЦ РК / Ахметов Е.З. [и др.]. - Алматы: ИЯФ НЯЦ РК, 1996.
3. Analysis and phased reconstruction of the radiation situation in the region of the "Galit" facility: report. - St. Petersburg.: NGO "Radium Institute", 1994. [in Russian]
   Анализ и поэтапная реконструкция радиационной обстановки в районе объекта "Галит": отчет. - СПб.: НПО "Радиевый институт", 1994.
4. On the artificial metamorphism of salt rocks: report. - St. Petersburg NGO "Radium Institute", 1967. [in Russian]
5. К вопросу об искусственном метаморфизме солевых пород: отчет. - Санкт-Петербург: НПО "Радиевый Институт" , 1967.
   Assessment of stability (instability) of rocks and localization of radionuclides at the facility "Vega" (Seitovsalt dome structures) and the contamination of subsoil: Report NEX. - Astrakhan: NGO "Radium Institute", 1994. [in Russian]

6. Оценка стабильности (дестабилизации) горных пород и локализации радионуклидов на объекте "Вега" (Сеитовская солянокупольная структура) и радиационное загрязнение недр: отчет НИС. – Астрахань: НПО "Радиевый институт", 1994.
7. Radioactive fallout from nuclear explosions / Yu. I. Izrael. – M. Mir, 1968. [in Russian]
   Радиоактивные выпадения от ядерных взрывов: [пер. с англ.] /под ред. Ю.И. Израэля. - М.: Мир, 1968.
8. Concept and Examples of Safety Analyses for Radioctive Waste Repositories in Continental Geological Formations. - IAEA Safety Series, 1983. - № 58.
9. V.V. Lobanova. The role of pyroclastic material in the formation of salt strata of the West Azgir uplift / V. V. Lobanova. - USSR, 1959. - T.125. - № 5. [in Russian]
   Лобанова В.В. Роль пирокластического материала в формировании соляной толщи поdaysтия Западный Азгир / В.В. Лобанова. - ДАН СССР, 1959. - Т.125. - № 5.
10. A.S. Krivohatsky. The main characteristics of the radiation situation after a series of underground nuclear explosions in the interests of the economy at salt dome field Great Azgir (Kazakhstan). Preprint RI-223 / A.S. Krivohatsky [et al]. - Moscow: NPO "Radium Institute", Central Research Institute "Atominform", 1992. [in Russian]
    Кривохатский А.С. Основные характеристики радиационной обстановки после завершения серии подземных ядерных взрывов в интересах народного хозяйства на солянокупольном месторождении Большой Азгир (Казахстан). Препринт РИ-223 / Кривохатский А.С. [и др.]. – М.: НПО "Радиевый институт", ЦНИИатоминформ, 1992.
11. General environmental assessment and forecast of the consequences of peaceful underground nuclear explosions on the biogeocoenosis of the areas adjacent to "Galit" facility: Report by the Institute of Ecology of the NTA. - Almaty: "Gylym shyny", 1995. [in Russian]
    Общеэкологическая оценка и прогноз последствий мирных подземных ядерных взрывов на биогеоценоз территорий, прилегающих к промплощадкам "Галит": отчет Института экологии НТА. - Алматы: "Гылым шыны", 1995.
12. Integrated ecological and economic study of natural areas and assessment of health status at Azgirs and Taysoygan test sites: report. - St. Petersburg.: Saint-Petersburg State University, 1992. [in Russian]
    Комплексное эколого-экономическое исследование природных территорий и оценка состояния здоровья населения на Азгирском и Тайсойганском полигонах: отчет. Ч. 2. - СПб.: Санкт-Петербургского Государственного Университета, 1992.
13. E. I. Preobrazhenskaya. Climatic principles in the study of radiation stability of higher plants / E. I. Preobrazhenskaya. - M., 1986. [in Russian]
    Преображенская Е.И. Климатические принципы изучения радиоустойчивости высших растений / Е.И. Преображенская. - М., 1986.

14. M.A. Pastushenko -Strelets. The critical period in shaping the radiation stability of seeds / M.A. Pastushenko -Strelets / /Journal of General Biology. - 1975. - T.36. - № 1. [in Russian]
Пастушенко-Стрелец М.А. Критический период в формировании радиоустойчивости семян / М.А. Пастушенко-Стрелец // Журнал общей биологии. – 1975. - Т.36. - № 1.
15. V.S. Shevchenko. The reasons for reducing the radionuclide content in the yield of crops when grown in infested soils / V.S. Shevchenko [et al]. // Uzbek biological journal. - 1984. - № 3. [in Russian]
Шевченко В.С. О причинах снижения содержания радионуклидов в урожае сельскохозяйственных культур при выращивании их на заселенных почвах / В.С. Шевченко [и др.]. // Узбекский биологический журнал. – 1984. - № 3.

АЗҒЫР ПОЛИГОНЫНДАҒЫ ЯДРОЛЫҚ СЫНАҚ ЗАРДАПТАРЫН ЖОЮ ЖӘНЕ ҚАЗІРГІ РАДИАЦИЯЛЫҚ ЖАҒДАЙ

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Мақалада "Азғыр" полигонында жерасты қуыстарын құру бойынша жұмыстарға шолу ұсынылып, ядролық жарылыстардың параметрлерін суреттеу, ұңғымалар мен жерасты қуыстарының жағдайы келтірілген. Радионуклидтердің қоршаған ортаға болжамды жылыстауының негізгі механизмдері қарастырылған. Жүргізілген радиоэкологиялық зерттеулердің нәтижелері және тұрақты мониторинг деректері полигон аумағы мен оған іргелес ауылдардағы қазіргі радиациялық жағдайдың бекітілген санитарлық-гигиеналық нормативтерден аспайтындығын көрсетті. Радиациялық қатерлерді төмендетудің қолданылған әдістері мен технологияларының тиімділігі туралы қорытынды жасалды.

ЛИКВИДАЦИЯ ПОСЛЕДСТВИЙ ЯДЕРНЫХ ИСПЫТАНИЙ НА ПОЛИГОНЕ АЗГИР И СОВРЕМЕННАЯ РАДИАЦИОННАЯ ОБСТАНОВКА

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В статье представлен обзор работ по созданию подземных полостей на полигоне "Азгир", приведено описание параметров ядерных взрывов, состояния скважин и подземных полостей. Рассмотрены основные механизмы возможной миграции радионуклидов в окружающую среду. На основании анализа результатов проведенных радиоэкологических исследований и данных постоянного мониторинга показано, что современная радиационная обстановка на территории полигона и в прилегающих поселках не выходит за пределы установленных санитарно-гигиенических нормативов. Сделан вывод об эффективности примененных методов и технологий снижения радиационных рисков.

УДК 577.4:504.064:539.16

DEVELOPMENT STRATEGY FOR THE PROJECT "COMPREHENSIVE RESEARCH AND MONITORING OF "LIRA" FACILITIES" *(based on the works performed in 1998–2010)*

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The paper reviews the studies performed by NNC for assessment of LIRA facilities radiological status, determination of the level and extent of in-deep contamination at the facility, as well as surface contamination at the adjacent lands and settlements. It also describes the basic principles of the developed science-based integrated system for monitoring of LIRA facilities and neighboring territories. We consider the threat model development in relation to LIRA facilities and radiation safety assurance concepts. The strategy for elimination of underground nuclear cavities at LIRA site has been substantiated.

1. HISTORY OF "LIRA"FACILITIES AND THE PROJECT "COMPREHENSIVE RESEARCH AND MONITORING OF "LIRA" FACILITIES"

The Karachaganak oil-gas condensate field (KOGCF) is located in Western Kazakhstan, 30 km from the town of Aksai in the West Kazakhstan oblast of Kazakhstan

In the late 1970s, the original project to develop and exploit KOGCF had an integral part of a single processing facility provided for making buffer underground tanks for technological control during gas and condensate transportation to the Orenburg gas processing plant. A conventional method for underground erosion to build the required capacity was not possible due to the short time allocated for the construction, lack of the necessary amounts of water for erosion at KOGCF territory, expected environmental contamination of large areas of lands with salts being accumulated. It was therefore decided to use special technology using underground nuclear explosions for construction of underground reservoirs.

In this regard, by the decree of the CPSU Central Committee and USSR Council of Ministers #239-96 dated 25.03.83, and #424-107 dated 08.05.84 on the project All-Union Research and Design Institute of Industrial Technology "VNIPIpromtehnologiya" coordinated with the 3rd General Directorate of Ministry of Health of the USSR, the Soviet Union State Hydrometeorology and approved by the Ministry of Medium Machine Building and gas industry in 1983 and 1984 in the salt thickness of KOGCF northern wing at depths of 840-960 m in pre-drilled holes along the river Berezovka the nuclear charges were exploded. The created underground tanks under the code name for an explosive designs were named – facilities "Lira-1" and "Lira-2" (Figures 1 and 2).

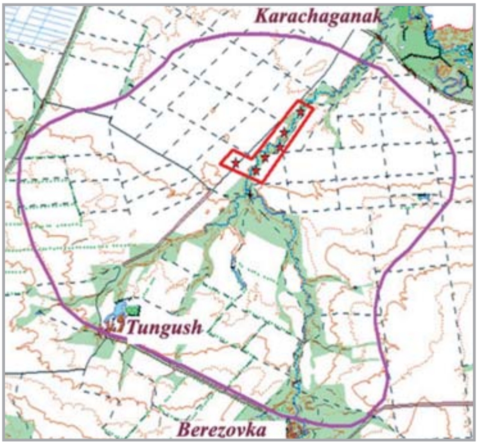


Figure 1. Karachaganak field and LIRA facilities' contours

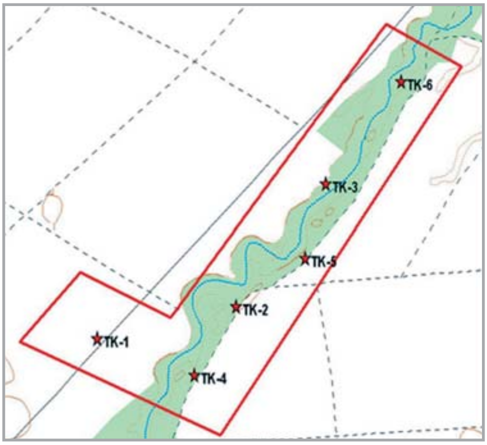


Figure 2. LIRA facilities layout

According to official figures provided by the institute "VNIPIpromtehnologiya" the underground nuclear explosions at the facility LIRA and the cavities are characterized by the parameters (Table 1).

Table 1.

1.1 Features of nuclear explosions and the cavities at LIRA site

Under-ground cavity	Date and time of explosion	Geographical coordinates latitude longitude	Explosion yield, kiloton	Depth, m	Volume, thous. m³	Condition of reservoir
TK-1	10.07.83 03.59.57	51°21'47' 53°18'21"	15	881	55	Used for the reception of the condensate. 13.6 thous. of ton condensate stored
TK-2	10.07.83 04.04.57	51°21'52' 53°19'21"	15	888	66	Used for the reception of the condensate. 50 thous. of ton condensate stored
TK-3	10.07.83 04.09.57	51°22'49' 53°20'19"	15	796	45	Used for the reception of the condensate. 15.2 thous. of ton condensate stored
TK-4	21.07.84 02.59.57	51°21'33" 53°19'09"	15	820	47	Used for the reception of the condensate. 4.6 thous. of ton condensate stored
TK-5	21.07.84 03.05.57	51°22'13" 53°20'11"	15	844	49	When opened it was watered
TK-6	21.07.84 03.09.57	51°23'31" 53°21'00"	15	931	49	At present there is a blockage in the borehole

Based on the information provided by the institute "VNIPIpromtehnologiya" and in accordance with the classification, these nuclear explosions were defined as complete camouflet explosions, i.e. explosions, which released radioactive substances in the quantities that could not harm the health of the population of the adjacent communities. However, according to unofficial information the witnesses observed outflow of gases during the explosion at the cavity TK-2.

In addition, the underground reservoir TK-5 at opening happened to be completely watered. The underground reservoir 5TK was opened through the hole drilled near 5RTK "bis".

After the preliminary operations, the explosion and subsequent opening and examination the underground tanks at boreholes 1TK, 2TK, 3TK, 4TK, 6TK were dry and consistent with the project volume.

In order to control the migration of radionuclides from the flooded reservoir 5TK, a network of control and monitoring boreholes 1KN-4KN depth of 350 m was set up, controlling aquifers of the cap rock, 12KN at depth of 1,250 m to control the aquifers of salt formation. In addition, towards the river Berezovka from the borehole 5TK there were drilled six boreholes RG-1 – RG-6, which control the water-bearing stratum of Neogene-Quaternary and Triassic sedimentations.

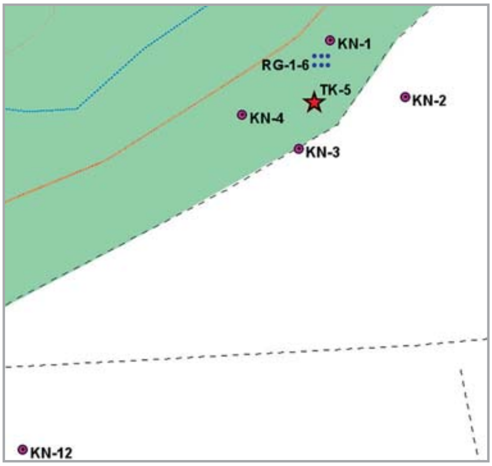


Figure 3. System of monitoring wells near cavity TK-5

Currently, the cavities TK-1 – TK-4 are technologically settled, partially filled with condensate and are under pressure up to about 40 atmospheres. The works on arranging cavity TK-6 were not completed due to technological accident. Later, to control cavity TK-5, a network of control-observation wells was set up (Figure 3).

Until 1998, LIRA facilities were owned and maintained by JSC "Karachaganakgazprom". Radiation monitoring and radioecological studies were carried out based on a limited number of parameters and were not performed systematically.

In accordance with the Cabinet of Ministers of the Republic of Kazakhstan dated January 12, 1998 # 5 LIRA facilities were transferred to the Ministry of Science - Academy of Sciences of the Republic of Kazakhstan and transferred to the balance of the Institute of Nuclear Physics (INP) of the National Nuclear Center (NNC) of the RK.

Based on the Final Production Sharing Agreement on the Karachaganak gas condensate field, an Agreement was concluded between JSC "National Oil and Gas Company" Kazakhoil" of the Karachaganak production structure and the NNC on the funding the research and monitoring at LIRA site. In order to coordinate the operations at LIRA facilities the Karachaganak production structure and the NNC RK developed and signed an Agreement on technical cooperation in comprehensive research and monitoring LIRA facilities.

2. INITIAL STATE OF AND INFORMATION ON THE FACILITY AT THE TIME OF TRANSFER UNDER NNC RK

At the time of LIRA facilities transfer under the responsibility of NNC RK, no regular information on the radioecological situation at the facilities was available in Kazakhstan. Specialists of the NGO "V.G. Khlopin Radium Institute ", which until 1993 controlled the state of LIRA facilities and left these facilities without noticing the Kazakh side, provided no information about its condition. By the time of transfer to the NNC RK we had only disembodied data on the exposure dose, total beta-activity and contents of cesium-137 at some points. Obviously, for a realistic assessment of the radioecological situation in relation to LIRA facilities these data had almost zero value. The wellhead platforms were hardly virtually fenced off, access to the site was free, and level of control was minimal. There were no results relative to the actual radioecological situation in the field and adjacent areas. The control and observation wells were arranged and, as was shown by the further geophysical works, were little serviceable.

The absolutely clear in this situation was a complete distrust of local authorities, regulatory and supervisory authorities of all levels to the data given in the Soviet period about the assurances of the radiation well-being at LIRA facility, a general distrust of the population to the activities of all organizations who had previously worked and controlled LIRA facilities and the extreme radiation phobia arisen as a result of complete lack of attention to the population shown by previous responsible organizations. Concerns of a strategic investor, who had no experience in large-scale oil and gas operations directly in the fields of nuclear explosions, about the safety of the oil and gas operations at KOGCF jeopardized the development of the Karachaganak project.

It should certainly take into account the objective complexities of restraining the operations on the full-scale research and monitoring LIRA facilities: remoteness of the site from the main production and analytical capacities (number of parameters to be measured within 1-2 days after sampling); the lack of elaboration in the world scientific practice and the complete absence in Kazakhstan of instrumentation and methodological support for a highly sensitive determination of the witness elements (chlorine-36, tritium); lack of instrumentation and methodological support and qualified personnel in Kazakhstan for multiple determination with the required sensitivity of artificial radionuclides in various environmental media.

3. MODEL OF THREAT IMPOSED BY LIRA FACILITIES AT THE INITIAL STAGE OF THE KOGCF DEVELOPMENT AND RADIATION SAFETY PRIMARY CONCEPTION

Fears of the public and the assumption of some specialists about the possibility of large-scale radioactive contamination at LIRA facilities had certain objective pre-conditions.

1. A known fact that the geological structure of the Karachaganak dome is described by a model of "broken plate" that is characterized by a large number of zones of fracturing and decompression, which are the most likely pathways for the radioactive gases migration during the underground nuclear explosion, was in the first place. As a result of applying this particular tectonics and the huge pressures that arise when conducting an underground nuclear explosion, it is quite possible that large amounts of rock and soil surface layers may have become contaminated with artificial radioactivity to the levels dangerous to humans. Upon that the locations of the bulk zones of contamination and their shape, extent and level of contamination cannot be predicted in advance. The seismic activities of the previously conducted underground nuclear explosions additionally contributed to the opening of individual fractures, making it easier to transport the gas fluids to the surface during subsequent or concurrent explosions.
2. The next objective pre-condition was the emergency water fillup of cavity TK-5 immediately after it was created as a result of an underground nuclear explosion, which resulted in a 50 000 cubic meters of liquid radioactive waste of high activity with high potential mobility. In combination with the fracturing and decompression zones in a salt dome cap this circumstance was an additional factor capable in adverse conditions to lead to massive radioactive contamination (Figures 4 and 5).
3. Intenseness also prevailed due to the above fact of unfavorable technological arrangement of cavity TK-6 and uncertainty of its state in this regard.
4. The objective cause of the social tension and public concerns was also lack of systematic and faithful information.

Mutually being formed and amplified, the above reasons led to a large number of negative publications in various media, which resulted in the recent article "The Karachaganak Secrets" in the newspaper "Ural Week" #16 from April 22, 2004, that alleged unfavorable radiation situation in the KOGCF territory.

Based on the above arguments, the specialists of the National Nuclear Center of RK have formulated the primary threat model of radiological hazards from LIRA facilities, whose main provisions are as follows:

- radioactive contamination spread over a large area and in a significant areas of crustal blocks;
- the cavities are leaky and are a source of additional radioactive contamination;
- there is a tendency for widening the contaminated areas.

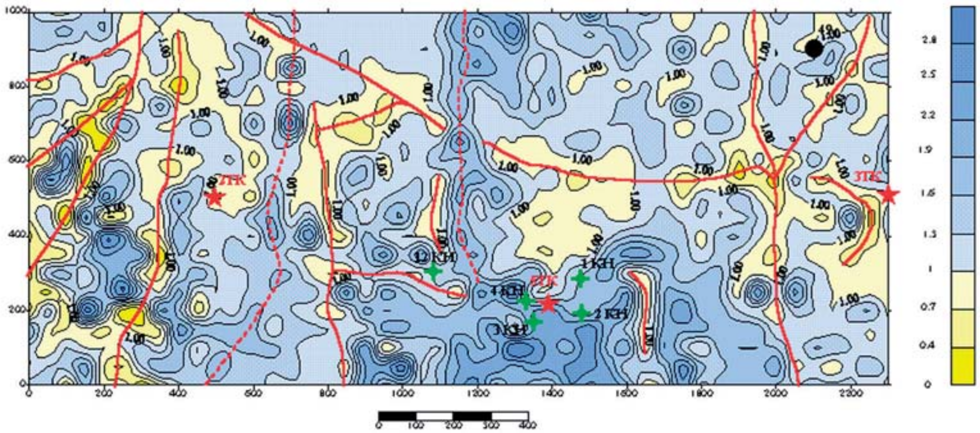


Figure 4. Revealed zones of fracturing and decompression at LIRA site

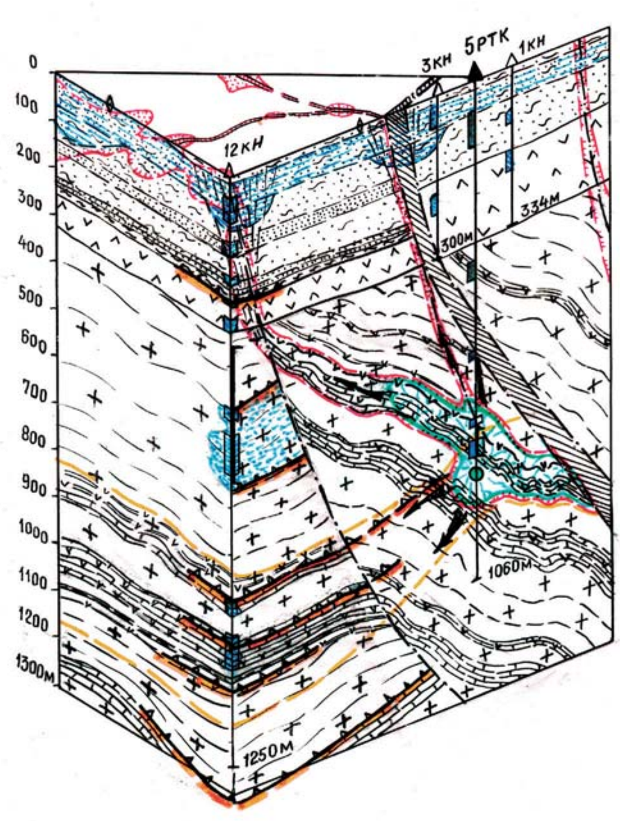


Figure 5. Possible three-dimensional model of groundwater migration zones in the block of rocks enclosing cavity TK-5, in the case of its collapsing

4. RADIATION SAFETY CONCEPT

To ensure long-term radiological safety of LIRA facilities and taking into account the formulated and adopted to test threat model, a concept was developed that includes the following basic activities:

1. Maintenance of LIRA facilities technological equipment in proper working condition.
2. Implementation of integrated monitoring, including radioecological, hydrogeological monitoring and monitoring of gas composition of subsoil air.
3. Preparation of material and technical basis to eliminate the potential emergency situations.
4. Technology development for immobilization of radionuclides in the cavities and its implementation.

The concept for ensuring the long-term radiological safety at LIRA facilities developed by the INP NNC RK was presented and discussed at the national and international levels. The most thoroughly it was reviewed in 1999 in Almaty at the International Scientific Workshop "Nuclear Physical Methods in Investigation of Radioecological Problems of the Former Nuclear Test Sites" (NATO Advanced Research Workshop) with participation of leading scientists from the USA, Europe and Russia including such world-renowned scientists as the former director of Los Alamos National Laboratory of the USA Z. Hecker and Director of the Russian Federal Nuclear Center R. Il'kaev, directly related to nuclear weaponizing. Based on the discussions, a protocol was adopted in which the workshop participants shared the opinion that with an appropriate technical implementation the proposed concept would provide long-term radiation safety of the nuclear cavities in the development of KOGCF, and proposed methods for achieving the goals are consistent with adopted world practice in execution of such works.

5. STUDIES BY THE NNC RK ON RADIOECOLOGICAL STATUS OF LIRA FACILITIES

To determine the actual radiological status of LIRA site and adjacent territories and to make grounded prediction of its development in 1998-2003, there were carried large-scale comprehensive studies which aim at/to:

- determine the level and extent of radioactive contamination of surface and subsurface soils in the territory of LIRA facilities and surrounding areas;
- determine the level and extent of deep radioactive contamination;
- determine possible pathways and intensity of radioactive contamination migration from cavity TK-5;
- determine the state of the cavity TK-6;
- development and creation of a complex monitoring system to obtain on a regular basis reliable information about radioecological conditions at LIRA facilities and its dynamics.

5.1. Determination of the level and extent of radioactive contamination of surface and subsurface soils at LIRA site

The first stage included a preliminary reconnaissance survey of the radiological situation in the territory of LIRA site and vicinities. The radiometric survey showed that the exposure-dose rate (EDR) in the area, with some exceptions, is in the range of 10-15 μR/h. At the site TK-5 there were revealed 2 spots with 0.5×1 m where the EDR is 20-30 μR/h, and directly at borehole TK-4 the EDR equals to 50 μR/h. The results from gamma-ray spectrometry of soil samples taken showed that the vast majority the concentration of artificial radionuclide ^{137}Cs is – n*10 Bq/kg. No other gamma-emitting artificial long-lived radionuclides (^{60}Co, ^{152}Eu, ^{154}Eu, ^{241}Am) were detected. Later the revealed areas with technological contamination were eliminated (Figure 6).

Figure 6. General view of the ground sampled at TK-4

To determine the level and nature of surface contamination, a detailed study of the artificial radionuclides content in the soil of LIRA site and adjacent areas was carried out. The study was aimed at clarification of the following main issues:

1. Revealing of indicators for proliferation of artificial radionuclides from a nuclear cavity to the surface.
2. Determination of indications for additional radionuclide contamination in connection with an evidence of noble gases outflow to the surface in preparation of the TK-2 for commissioning.
3. Overall assessment of the level and nature of the radionuclide contamination in the area surveyed;
4. Clarification of the mechanisms that stipulated the actual radiological situation at LIRA site and its surroundings.
5. Assessment of the radiological environment and dose loads on population living in the settlements adjacent to the LIRA site.

5.2. Radiation survey of surrounding areas and settlements

5.2.1. Experiment

The first stage included a preliminary reconnaissance survey of the radiation situation at LIRA site and vicinity. The radiometric survey showed that the exposure-dose rate (EDR) in the area, with some exceptions, is in the range of 10-15 µR/h. At the site TK-5 there were revealed 2 spots with 0.5×1 m where the EDR is 20-30 µR/h, and directly at borehole TK-4 the EDR equals to 50 µR/h. The results from gamma-ray spectrometry of soil samples taken showed that the vast majority the concentration of artificial radionuclide ^{137}Cs is – n*10 Bq/kg. No other gamma-emitting artificial long-lived radionuclides (^{60}Co, ^{152}Eu, ^{154}Eu, ^{241}Am) beyond the method sensitivity <1 Bq/kg were detected. However, some areas were revealed where the concentration of ^{137}Cs > 100 Bq/kg - technological contamination. Based on these results a remediation was carried at the most contaminated spots.

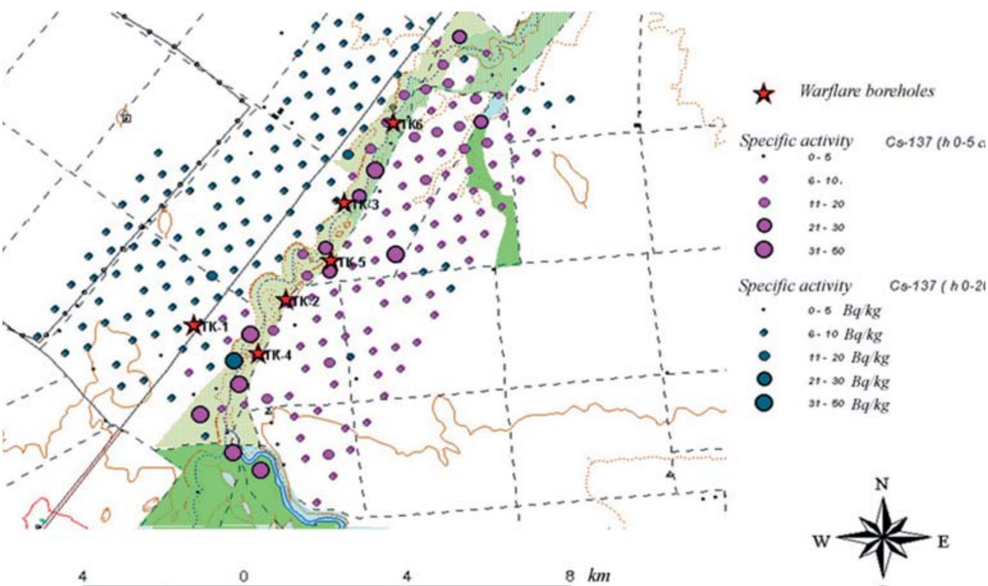


Figure 7. Distribution of ^{137}Cs at site "Central", surface soil (virgin land - 0÷5 cm; arable land - 0÷20 cm)

Statistical analysis of the results also revealed one more feature: the frequency of the relatively high (> 30 Bq/kg) concentration of ^{137}Cs to the maximum extent corresponds to the floodplain of the Berezovka River that is in close proximity to the emplacement boreholes. The further more detailed studies confirmed this preliminary finding (Figure 7). This feature strengthened the hypothesis (being developed in the IGR NNC RK) with respect to the presence of a constant proliferation of artificial radionuclides from the sprung cavities to the surface through the zones of decompressing and fracture porosity in the crust. Along with this hypothesis, the members of the INP NNC RK proposed another possible mechanism that led to the above-mentioned anomalies radionuclides proliferation from the surface of the entire contaminated (global fallouts, man-made pollution, seepage of the inert gases) territory to the floodplain of the Berezovka River with melt and rain waters. To ascertain the viability of these mechanisms, a number of special investigations was carried out, which are described below.

In accordance with the results of geophysical studies, with the active participation of the IGR NNC RK there was drafted the scheme for setting up the laying survey pit and layer-wise (10 cm) sampling of soil was carried out to a depth of 1.6 m (Figure 8).

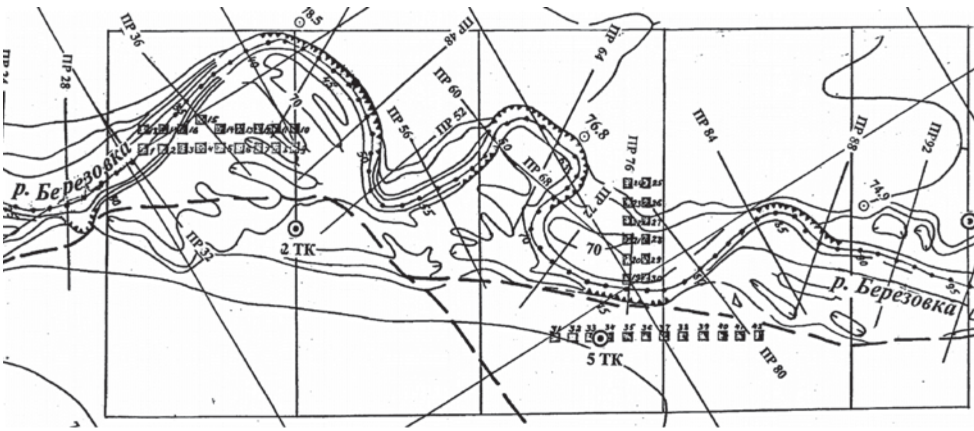


Figure 8. Sampling layout for deep layerwise soils (survey pits)

A gamma-spectrometry (to determine the ^{137}Cs) was carried out to analyze all 600 layerwise soil samples taken from 42 survey pits (Figure 9). The ground of individual survey pits (where ^{137}Cs is shown at the greatest depth) was analyzed by the radiochemical method (for determining ^{90}Sr and $^{239+240}Pu$). The results obtained allow the following conclusions:

- for the vast majority of survey pits the ^{137}Cs is concentrated in the upper soil layer, up to 20-30 cm;
- some exceptions for survey pits No. 1, 14, 15, 16, 19, 30, 34, 41, characterized by the presence of ^{137}Cs in the lower horizons, but no deeper than 70 cm; the ^{90}Sr, which has a higher migration ability, appears deeper but the nature of its distribution is similar to ^{137}Cs for its depth;
- $^{239+240}Pu$ as well as ^{137}Cs are detected (at concentrations of 0.2-0.7 Bq/kg) only in the upper layers to a depth of 70 cm; no any patterns in the nature of its distribution in depth were detected;
- the above-mentioned exceptions can be explained by the belonging of these survey pits to the floodplain of Berezovka River;
- all the results obtained (including the landscape features) strongly suggests the mechanism for redistribution of radionuclides from the surface into deep into the soil, but not vice versa.

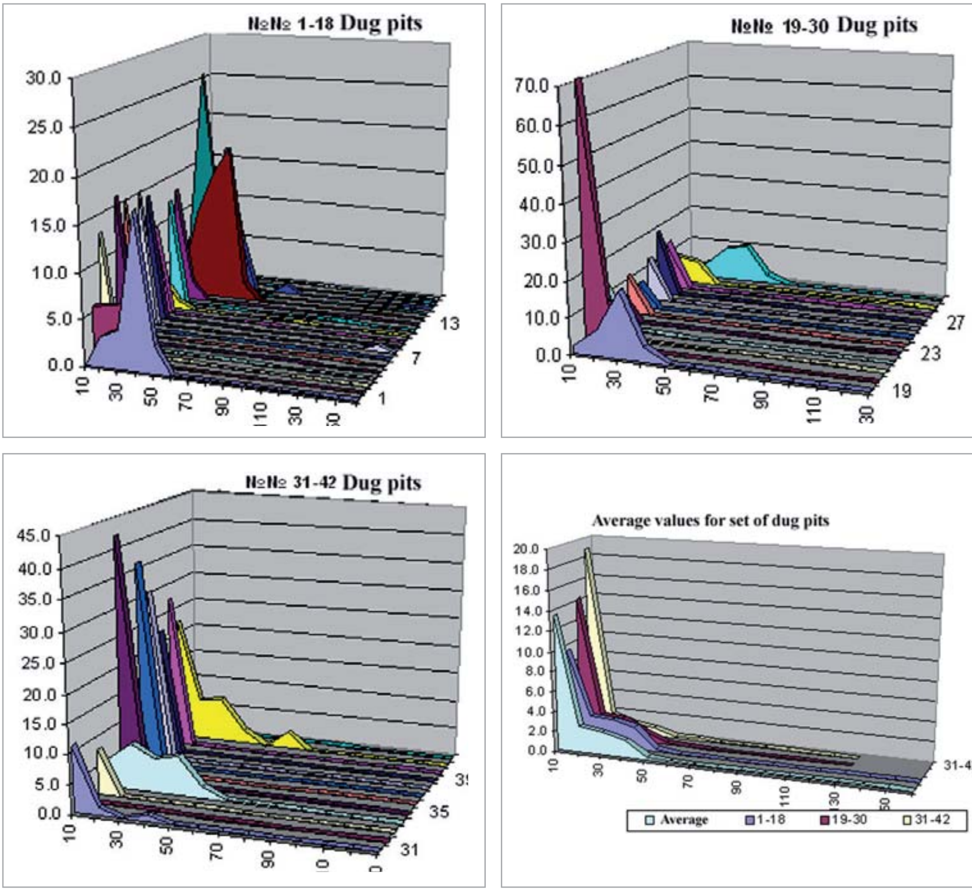


Figure 9. Distribution of cesium-137 in the depth of survey pits

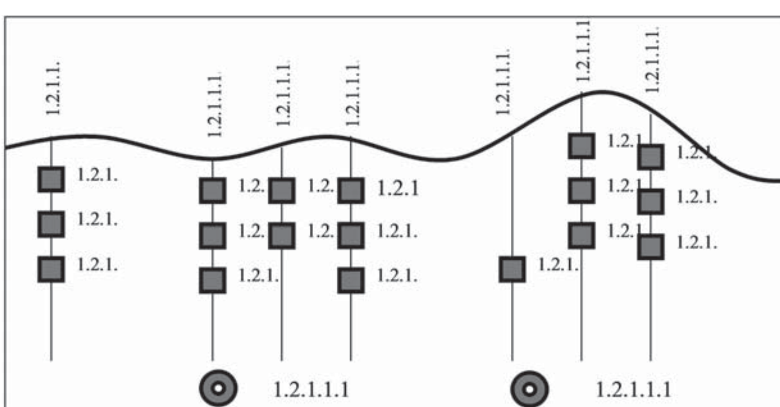


Figure 10. Layout of survey pits in the floodplain of Berezovka River

Note: Distance from the survey pit 52 to Pit-53A = 40 m. Total survey pits - 18 pcs Ш- шурф??? Тогда Pit

In order to further verify the above findings and upon the insistence of the colleagues from IGR NNC RK this experiment was repeated. Upon that, all the 18 survey pits (to a depth of 1 m) were laid entirely in the floodplain of Berezovka River opposite boreholes TK-2 and TK-4 (Figure 10). The selection of sites for laying these survey pits was based on the fact that only in those locations, according to earlier results, the concentrations of ^{137}Cs in the lower soil layers (50-70 cm) exceeded those for the upper (0-20, 20-50 cm) layers.

According to the results from gamma-spectrometric analysis of these samples, a graphical distribution of ^{137}Cs in the soil depth for each survey pit separately was constructed. Figure 11 shows these distributions for individual survey pits where ^{137}Cs was found at very low horizons. None of the 18 surveyed pits, as all others, had significant concentrations of ^{137}Cs deeper than 70 cm. The obtained results confirmed the consistency of the conclusion about the absence of a mechanism for radionuclides inflow from the bowels to the earth's surface.

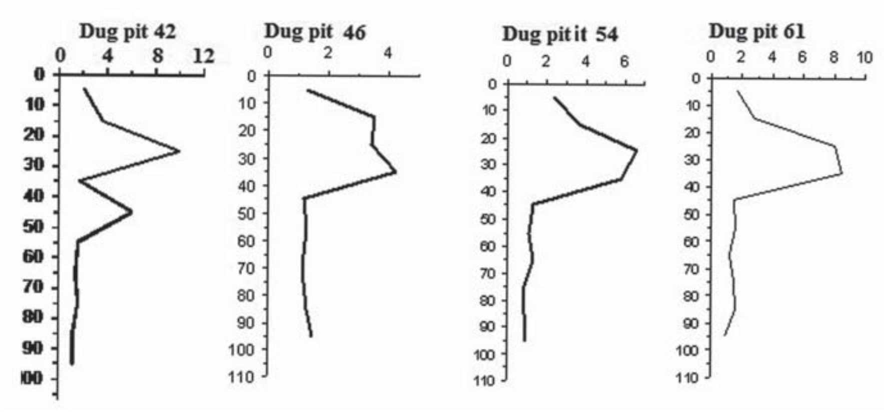


Figure 11. Distribution of ^{137}Cs in the layerwise soil samples from the survey pits in the floodplain of Berezovka River.

Further studies to identify the contamination mechanisms in the immediate vicinity of LIRA facilities were continued in the basin of Berezovka River, as part of the most probable concentration of radionuclides due to their surface migration under the influence of environmental factors. At the same time, another attempt was to detect possible mechanism for the radionuclides proliferation from the subsurface directly into the river bed. For this purpose the bed of Berezovka River (including tributary Kunshubay) on the segment with length of 26 km was divided (by 50 m) into 514 survey stakes (Figure 12). At each survey stake from the two intervals of depths (0-25 cm and 25-50 cm) the bottom sediments were sampled. In addition, at 10 survey stakes (No. 6, 42, 70, 127, 260, 309, 341, 361, 379, 401) survey pits were laid to a depth of 1 m. The bottom sediments were sampled in the survey pits on five intervals, after 20 cm. The soil sampling in the floodplain was carried out (in the interval from zero to 156th stakes) from three depth intervals (0-20 cm, 20-50 cm, 50-70 cm). Part of the samples was taken with intervals in depth of 10 cm. Total 516 soil samples were taken from the floodplain.

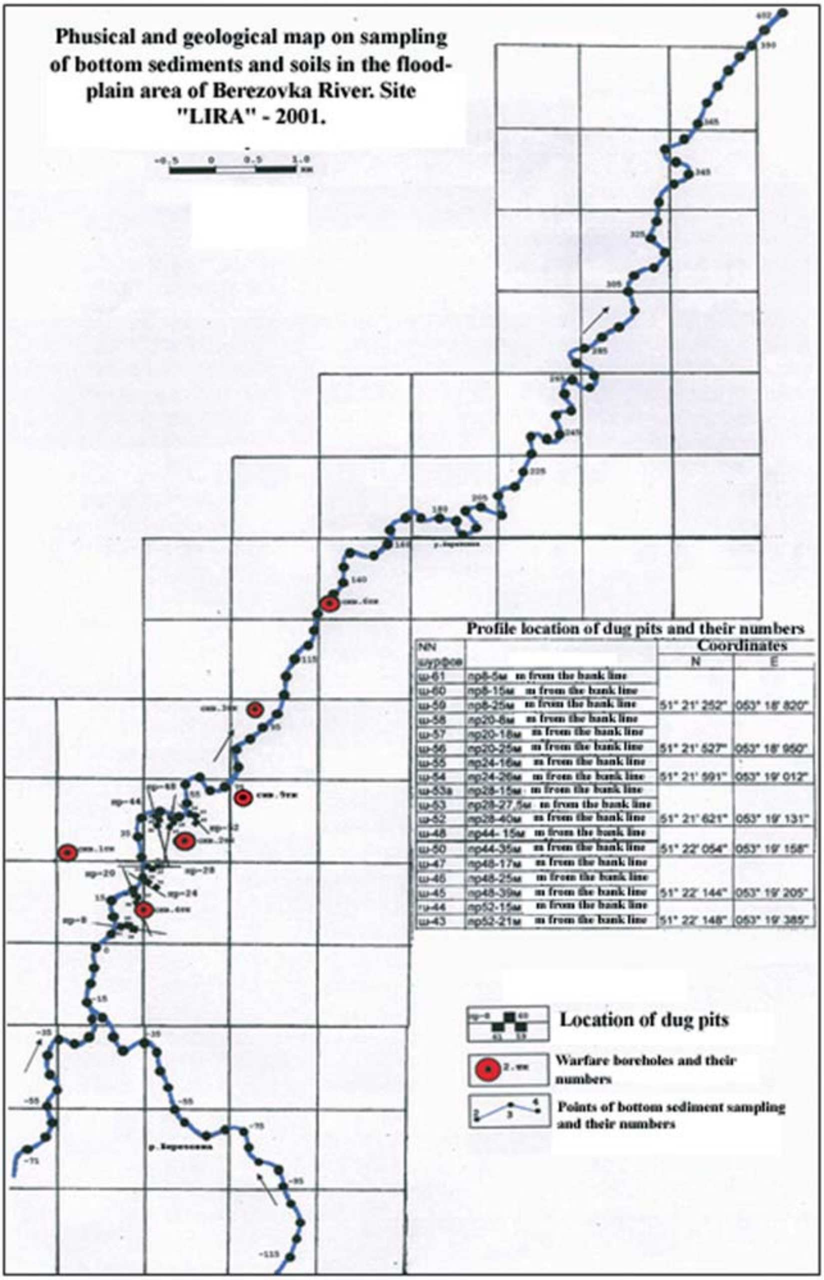


Figure 12. Sampling of soil and sediment in the floodplain of Berezovka River.

All the samples taken (more than 1,500) were analyzed employing gamma-ray spectrometry to determine the concentrations of ^{137}Cs. Part of the samples (approximately 10%) was studied by the radiochemical method of analysis for the determination of ^{90}Sr and $^{239+240}Pu$.

Based on the findings, we plotted the radionuclides distribution (averaged values) in depth of soil (Figure 13) and bottom sediment (Figure 14), respectively, in the flood plain and Berezovka river bed. It is seen that in the floodplain the maximum concentration of ^{137}Cs corresponds to the depths intervals of 20-30 cm; deeper its concentration decreases. In the bottom sediments, ^{137}Cs and $^{239+240}Pu$ maximal concentration corresponds to the depths intervals of 40-60 cm; deeper their concentrations decrease also.

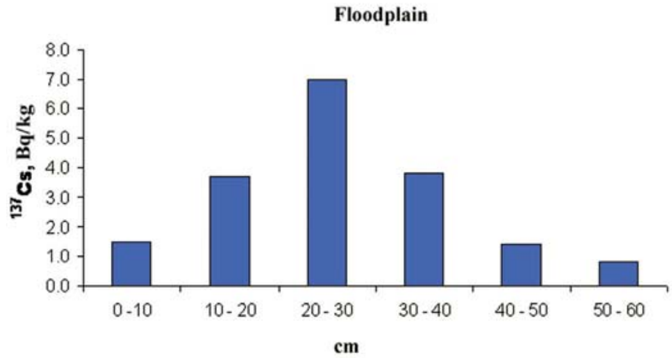


Figure 13. Distribution of ^{137}Cs (averaged values) over the depth of soil in the Berezovka river basin

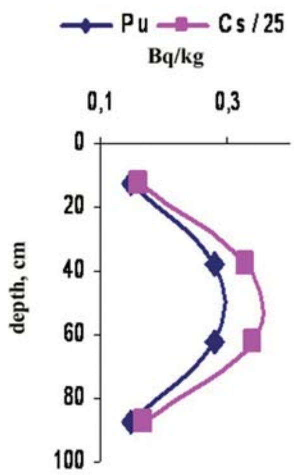


Figure 14. Distribution of ^{137}Cs and $^{239+240}Pu$ (averaged values) over the depth of bottom sediments in the Berezovka river basin

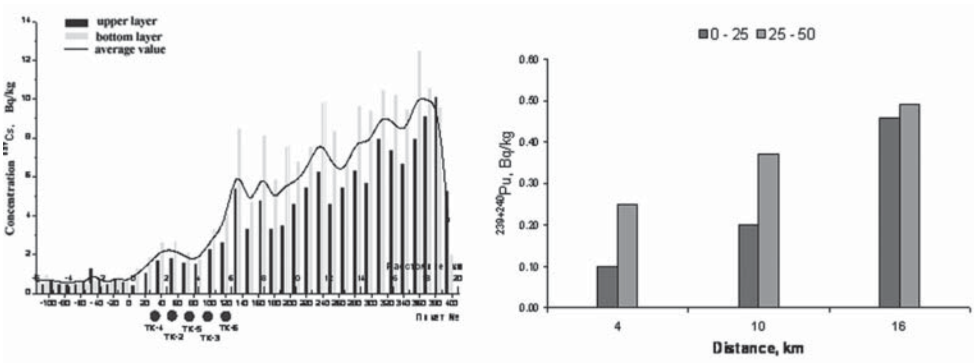
The totality of the results in the numerous studies on the nature of vertical distribution of artificial radionuclides provides a complete foundation for a final conclusion on the inconsistency of the hypothesis about the radionuclide contamination at LIRA site on the basis of the mechanism for radioactivity proliferation from the cavities in the earth's crust. In this regard, our further consideration has been based on a mechanism of surface redistribution of radionuclides.

Based on study results of the radionuclide composition of the bottom sediment we constructed a graph of ^{137}Cs and $^{239+240}Pu$ distribution along the Berezovka river bed. The results are shown in Figure 5.10 (a, b). It is seen that the concentrations of these radionuclides significantly increase moving down the river. It should be emphasized that the change in the concentrations of radionuclides starts with a segment of the river adjacent to the LIRA site (with the zero stake and below). In the upper reach of Berezovka River (a segment with length of 6 km) and its tributary Kunshubay (a segment with length of 2 km) the bottom sediments contain small quantities of radionuclides (mainly, concentration of $^{137}Cs \leq 1$ Bq/kg). The revealed features are persuasive evidence that the vicinity of the LIRA site (stakes: 20-120) is a source of additional (to the global fallout) radionuclide contamination of Berezovka river bed. The mechanism for this contamination is most likely the migration of radionuclides to the river with melts and rain waters. A wind-driven transport mechanism is also possible.

In 2009, Berezovka river bed was resurveyed, during which at 19 control points doses of x-ray and gamma-ray were measured, 180 samples were taken from the bottom sediment from two (0-25 cm and 25-50 cm) horizons, and 25 layerwise samples were taken from the bottom sediments (5 survey pits) after 20 cm with a depth of up to 1 m. Water samples were taken at four control points for subsequent laboratory studies. It is established that MD rates at all control points remain in the range (0.08 - 0.15) µSv/h, which corresponds to the background in this region.

The combined radionuclide composition of sediment samples were examined using instrumental gamma-ray spectrometry and radiochemical analysis; it was found that the concentration of NRN corresponds to background values, ^{137}Cs concentration in all layers of bottom sediments in Berezovka River is obviously elevated, but is not harmful to living organisms. The distribution of this radionuclide in the sediment sampled in 2009 along the bed of this river, in general, corresponds to that for the period of 2001. Elemental composition of the bottom sediments sampled at two horizons and with the survey pits (5 horizons) in the Berezovka river bed were studied by NAA (neutron activation) and X-ray fluorescence (XRF) methods. The obtained results indicate that concentrations of most of the determined elements are within the values of their clarke. In the bottom sediments of the lower layers of the survey pit # 250 large contents of Ca, Ba, and Pb were discovered. It was revealed at the same time that the concentration of lead in the bottom sediments of the layer (60-100) cm of the survey pit exceeds the maximum allowable concentration (MAC) value corresponding to this element in the soil (32 µg/g) for more than 2 times.

According to the re-survey results a conclusion was made that the radiation and ecological situation in the basin of Berezovka River is normal and in the period 2001-2009 did not change. A number of circumstances were revealed that require clarification through more detailed studies.



a) *b)*

Figure 15. ^{137}Cs (a) and $^{239+240}$Pu (b) distributions in the sediments sampled along the Berezovka river bed

In connection with the revealed fact, it was decided to conduct a detailed radiological survey of LIRA site. This site covers about 31 km^2, within which 70% (mostly left bank of Berezovka River) is used and abandoned arable land and the rest - the natural virgin landscapes. The whole territory was broken down and sampled within the grid 500×500 m plus 1 point in the center ("envelope" scheme). Some areas were subjected to more detailed examination. Soil sampling for further laboratory investigations was carried out differentially: on the virgin lands 3 samples were taken (0-5 cm, 5-10 cm, 10-30 cm) at each control point, on the arable lands - 2 samples (0-20 cm, 20 -30 cm). During the sampling, radiometric measurements were also carried out. The recorded EDR values ranged from 9 to 15 μR/h, which correspond to the background in this region, due to the natural radionuclides and global fallouts. All the samples taken (total 3,790 samples) were investigated by gamma-spectrometric method of analysis (^{137}Cs, ^{228}Th, ^{226}Ra, ^{40}K). Part of the samples (approximately 10%) was subjected to radiochemical analysis (^{90}Sr, $^{239+240}$Pu). No any peculiarities in the content and distribution of natural radionuclides were detected. Concentrations of $^{239+240}$Pu in the studied samples remain within the intervals: (<0.05-2) Bq/kg, ^{90}Sr - (<5-20) Bq/kg. Table 2 shows the average concentrations of ^{137}Cs in different soil layers on the virgin and arable lands of the surveyed territory.

Table2.

Average values of ^{137}Cs concentration in different soil layers in LIRA facilities territory (site "Central")

Soil state	Virgin land				Arable land			Average
soil layer, cm	0–5	5–10	10–30	0–30	0–20	20–30	0–30	0÷30
^{137}Cs, Bq/kg	10.7±8.8	7.0±4.2	3.5±2.6	5.3±3.0	7.1±1.4	5.4±1.8	6.5±1.2	5.9±3.1

According to various literature sources and reference materials, the average background level due to global fallouts for the northern hemisphere mid-latitudes lies in the following ranges, Ci/km^2: ^{137}Cs - (0.08-0.15); ^{90}Sr - (0.045-0.070); $^{239+240}$Pu - (0.001-0.005). For 0-5 cm soil layer, these values correspond to the following concentrations, Bq/kg: ^{137}Cs - (37-69);

^{90}Sr - (21-32); $^{239+240}Pu$ - (0.46-2.3). Accordingly, for the 0-30 cm layer, Bq/kg: ^{137}Cs - (6.2-11.5); ^{90}Sr - (3.5-5.3); $^{239+240}Pu$ - (0.077-0.38). Comparing these data with published ones, we can conclude that the level of radionuclide contamination at the LIRA site is within the background values.

Based on the analytical data, the following features may be noted: for all layers of the soil the areal distribution of ^{137}Cs is more uniform (20-30% of variance) than on the virgin lands (60-80% of variance). The distribution gradient of this radionuclide in depth on the virgin lands is also greater than on the arable lands. The average concentration of ^{137}Cs in the soil layer 0-30 cm on the arable land (up to 18%) exceeds that of the virgin lands. All these features provide a basis for concluding that the plowing leads to the homogenization of radionuclide concentrations both horizontally and in depth of the soil and prevents their spatial migration.

The ^{137}Cs overall distribution pattern (soil layer 0-30 cm) at the LIRA site is described in terms of isolines in Figure 16. It is seen that, in general, this radionuclide is uniformly distributed. Certain anomalies with a high content of it, as mentioned above, are involved mainly in the floodplain of Berezovka River. This may well be explained by proliferation of the radionuclides from the surface of the entire contaminated area to the riverbed. A confirmation for this mechanism may be a pattern of ^{137}Cs distribution (averaged values) by the stakes on the virgin lands of the LIRA site (Figure 17). It is seen that the concentration of this radionuclide in the upper soil layers significantly increases from the periphery to the center (from stake 1 to stake 9), that is towards the Berezovka river bed.

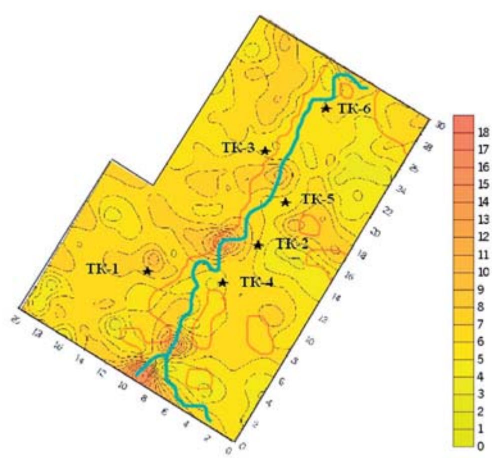


Figure 16. ^{137}Cs distribution, Bq/kg for the site "Central", layer 0÷30 cm

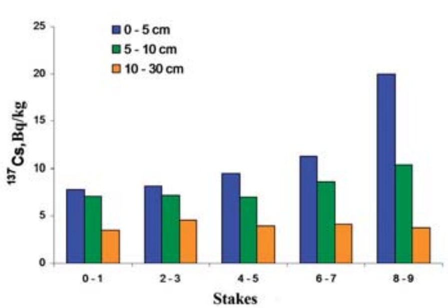


Figure 17. ^{137}Cs distribution by stakes on the virgin area of LIRA site

The survey at the LIRA site did not reveal any explicit signs of the trace from the radioactive fallouts from the release of radioactive gases at the TK-2. The uncertainty on this issue necessitated the large-scale surveys of the territories surrounding LIRA facilities, including KOGCF and nearest settlements. The general scheme of examination of these areas is presented in Figure 17. The methodology of this areal survey (excluding the settlements) is broadly consistent with the methodology for the LIRA site surveying. Sampling was also performed differentially, depending on the condition of the soil (virgin, arable lands). The sampling scheme was "envelope", but sampling increments was larger: 1000×1000 and plus 1 point in the centre. Radiometric measurements were carried out at each control point, which revealed the same EDR level (9-15 μR/h) corresponding to the background value in the region. In total, according to the diagram (Figure 18) for laboratory tests, more than 4,000 soil samples were taken. Currently, the bulk of these samples (> 90%) have been studied employing gamma-ray spectrometry (^{137}Cs) and, in part, radiochemical (^{90}Sr, $^{239+240}Pu$) methods. The results showed that the concentrations of $^{239+240}Pu$ in these areas do not exceed 1.5 Bq/kg, the concentration of ^{90}Sr is in the range up to 15 Bq/kg, the maximal concentration of ^{137}Cs do not exceed 60 Bq/kg.

Figure 18. Areal radiological surveying in the outskirts of LIRA facilities

Based on the findings, a numerous graphical representations were made for areal distribution of the artificial radionuclide ^{137}Cs in different soil layers. Figure 19, in the form of contour lines, shows the distribution of the radionuclide (soil layer 0-30 cm) by areas of the six sectors, including the LIRA site (site "Central"). All efforts to find a trace from the radioactive fallouts failed. The resulting distribution (Figure 15) in its nature is fully consistent with the distribution of global fallout. In general, all the surveyed areas are characterized by a single degree of contamination with radionuclides. All existing irregularities are quite explainable by the topography features.

In order to investigate the possible influence of LIRA facilities on the radiation situation in the settlements, a nature of changes in ^{137}Cs concentrations was studied as moving away from the site. Table 3 shows the average values of its concentration (0-30 cm soil layer) for all sectors surveyed after every 4 km from the boundary of the LIRA site. The data listed in Table 5.1, do not provide a basis for determining the presence of such substances. A statistical processing of the experimental data set average (for the entire surveyed area) values for all ^{137}Cs concentrations in all sampled soil layers. The results are shown in Table 4.

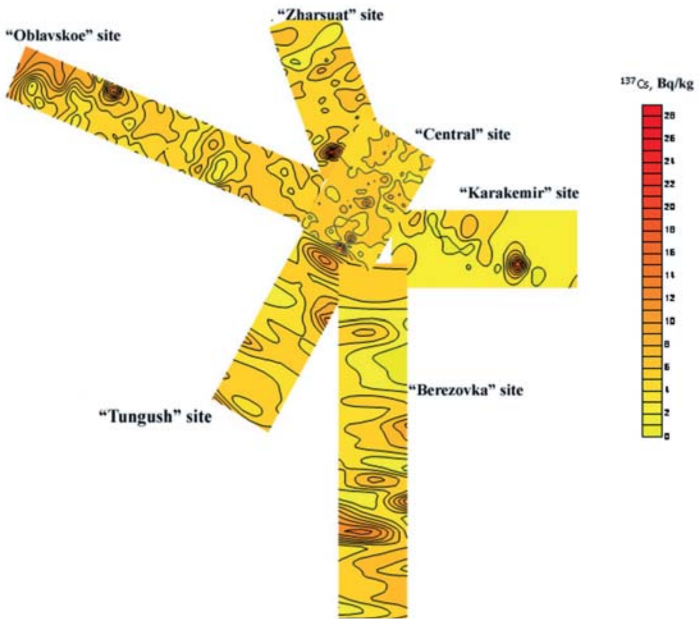


Figure 19. Areal distribution of ^{137}Cs (for the soil layer 0-30 cm) in various sectors

Table 3.

^{137}Cs average concentrations in soil samples (0-30 cm layer), taken from the territories of all surveyed sectors, Bq/kg

Sector	Distances from the territory of LIRA facilities, km						Average
	0 - 4	5 - 8	9 - 12	13 - 16	17 - 20	21 - 24	
Zharsuat	7.5 ± 3.2	6.7 ± 3.0	6.2 ± 2.9	7.5 ± 3.1	-	-	7.0 ± 3.0
Oblavskoe	6.4 ± 2.8	6.5 ± 2.5	5.7 ± 2.4	6.2 ± 2.4	6.7 ± 2.3	7.7 ± 3.0	6.5 ± 2.5
Tungush	7.0 ± 2.9	6.5 ± 2.5	6.6 ± 2.4	-	-	-	6.7 ± 2.5
Berezovka	5.3 ± 2.2	3.4 ± 1.7	6.9 ± 3.0	5.7 ± 2.5	8.8 ± 2.6	7.6 ± 3.1	6.3 ± 2.3
Karakemir	-	6.4 ± 2.3	6.2 ± 2.3	6.5 ± 2.4	5.9 ± 2.2	-	6.3 ± 2.3
Average	6.6 ± 2.3	5.9 ± 2.2	6.3 ± 2.3	6.5 ± 2.4	7.1 ± 2.4	7.4 ± 3.0	6.6 ± 2.4

Table 4.

^{137}Cs average concentrations in different soil layers in vicinity of the LIRA site

Soil type	Virgin land			Arable area		Average
soil layer	0 - 5	5 - 10	10 - 30	0 - 20	20 - 30	0 - 30
^{137}Cs, Bq/kg	12.0 ± 3.7	8.7 ± 2.4	4.7 ± 2.1	7.0 ± 1.5	5.8 ± 1.3	6.6 ± 1.4

Limited data on ^{90}Sr, $^{239+240}Pu$ determination (due to labour-intensiveness of the analyses) does not give grounds for an unambiguous conclusion about the average (for all the surveyed areas) concentrations of these radionuclides. In addition, for the radiochemical analysis, as a rule, soil samples were taken from the most contaminated sites. However, the resulting set of experimental analytical data provides a basis for concluding that the average values of their concentrations in the soil layer 0-30 cm is reliably limited to the following limits: $^{239+240}Pu \leq 0.3$ Bq/kg, $^{90}Sr \leq 5$ Bq/kg. These data suggest that the level of radionuclide contamination in the 20-kilometer outskirt of the LIRA site is within the background values.

When choosing a radiation survey objects, the recommendations of the International Commission on Radiological Protection were taken into account. According to these guidelines, it is urged to take into consideration the social factors considering that the presence of potentially dangerous objects on populated territory is a stress factor. In this regard, the list of the survey objects included all 16 communities located in the vicinity of LIRA site: Akbulak, Aksai, Aksu, Berezovka, Bestau, Burlin, Dmitrov, Zhanatalap, Zharsuat, Karakemir, Karachaganak, Oblavskoe, Priuralnoe, Pugachevo, Tungush, Uspenovka.

All the settlements were surveyed with the single methodology. Within each settlement 20 points and 20 points - on the perimeter were set for soil sampling. At each point soil samples were taken with a sampler S = 0.01 m^2, layerwise: 0-5 cm, 5-10 cm, 10-30 cm. The water samples (2 samples at each settlement) were taken from boreholes and water supply system. At each location 3 water samples with a volume of 1.5 liters were taken. Samples of vegetation (2 samples at each settlement) were taken from the hay harvested by the residents.

Geographical coordinates at all sampling points were determined employing GPS controller. Concentrations of radon in the air were measured in all settlements, in living rooms and basements - 10 measurements in each settlement. The results of these measurements are shown in Figure 20. Exceeding over the sanitary standards (200 Bq/m^3) was found in a residential area of the village Zhanatalap (390 Bq/m^3) and in many cellars (up to 5,000 Bq/m^3) in various settlements.

EDR was measured in all sampling points using the dosimeter-radiometer DKS-96 5 cm and 1 m above the ground. The results of these measurements showed that the EDR is 7-15 μR/h and are within background levels for this region.

The radionuclide composition of soil samples (^{137}Cs, ^{40}K, ^{226}Ra, ^{228}Th) was employing gamma-spectrometric method. At present, more than 80% of all samples were analyzed. Table 5 shows the concentrations of natural radionuclides in soils in all 16 settlements. The average concentrations of these radionuclides were also determined in all examined settlements, Bq/kg: ^{40}K - 588; ^{226}Ra - 23.6; ^{228}Th - 32.1.

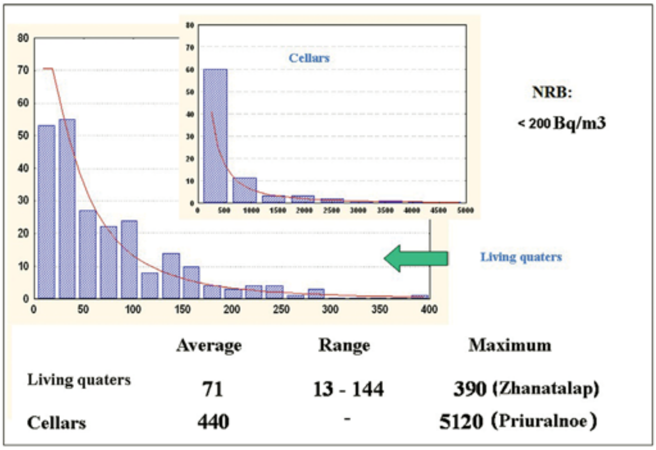


Figure 20. Volumetric activity of ^{222}Rn (Bq/m^3).

Table 5.

Specific activity of natural radionuclides in the soils of the settlements

Settlement	^{40}K (Бк/кг)	^{226}Ra (Бк/кг)	^{228}Th (Бк/кг)
Akbulak	528	22,9	31,7
Aksaj	495	21,5	25,8
Aksu	543	18,3	24,9
Berezovka	522	27,1	33,3
Bestau	493	17,6	25,1
Burlin	635	27,6	34,7
Dmitrov	622	19,9	29,6
Zhanatalap	665	22,5	30,7
Zharsuat	569	26,9	32,3
Karakemir	681	25,7	38,0
Karachaganak	648	22,3	35,3
Oblavskoe	550	26,2	30,8
Priural'noe	624	22,3	33,6
Pugachevo	603	20,3	32,9
Tungush	599	26,3	25,9
Uspenovka	630	23,2	35,0
n	1529	1529	1529

Table 6 shows concentrations of ^{137}Cs (average values) in the soil of the 16 settlements for layers 0-5 cm, 5-10 cm 10-30 cm and 0-30 cm. All these values are within the background for this region. The maximal concentration of ^{137}Cs (average values) for soil layer 0-5 cm corresponds to the village Karachaganak. It cannot be ruled out that this is due to minor sources of radioactive gases at the TK-2, a plum of which, according to eyewitnesses, propagates towards the village. However, these concentrations do not pose any threat to public health.

Table 6.

Specific activity of ^{137}Cs in different soil horizons of the settlements (Bq/kg)

Settlement	Soil layer			
	0-5 cm	5-10 cm	10-30	0-30
Akbulak	9.9	6.4	4.2	5.5
Aksaj	17.8	6.5	2.3	5.6
Aksu	8.5	5.8	5.0	5.7
Berezovka	16.8	6.0	3.5	6.1
Bestau	11.6	7.0	4.6	6.2
Burlin	20.5	3.6	2.1	5.4
Dmitrov	21.7	7.3	2.9	6.8
Zhanatalap	8.8	4.1	2.3	3.7
Zharsuat	14.4	--	--	--
Karakemir	13.5	5.4	3.2	5.3
Karachaganak	29.2	--	--	--
Oblavskoe	14.8	--	--	--
Priural'noe	11.9	7.9	3.3	5.5
Pugachevo	9.6	3.5	3.4	4.5
Tungush	15.6	8.7	4.5	7.0
Uspenovka	12.1	7.7	4.2	6.1
Average	14.8	6.1	3.5	**5.6**

Radionuclide composition in water and vegetation samples was studied employing both instrumental and radiochemical analytical methods. The main results of these tests are shown in Figure 21.

The effective dose loads on the population of villages surrounding LIRA facilities was calculated. The total dose load ranges from about 2,000 to 6,000 μSv/year, and, the main dose is accounted for inhalation intake of radon and thoron. Except for this source, the dose from other sources is about the same (Figure 22).

The diagram (Figure 23) shows the distribution of the average effective dose load on the population of the villages. As it can be seen, the main dose load is due to inhalation of radon daughters 43.6%; artificial radionuclides contribute only for 0.1%.

Thus, it was found that after deduction of radon and thoron inhalation rates, the radiation environment in the settlements around LIRA site is almost the same as in other places. In general, the radiation situation is normal. No impact of LIRA facilities on the radioecological situation in the villages was found.

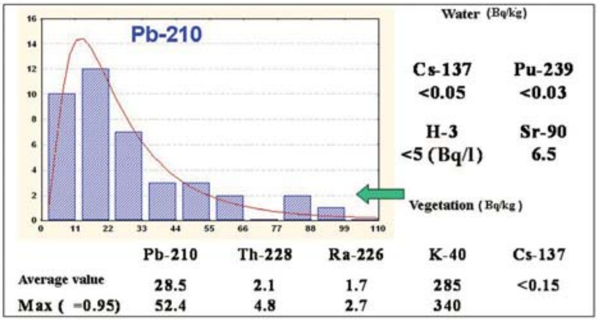


Figure 21. Effective dose loads to the population of villages surrounding LIRA facilities

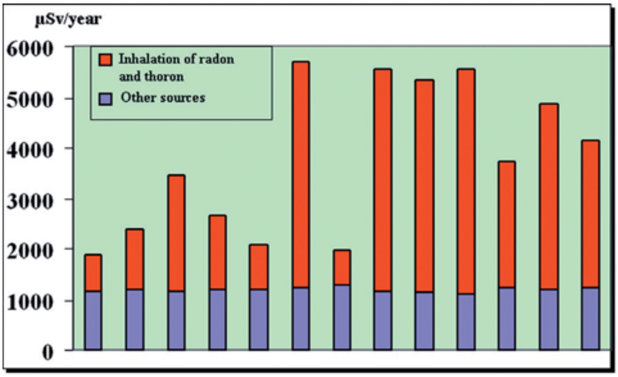


Figure 22. Specific activity of natural and artificial radionuclides in water and vegetation sampled in the settlements

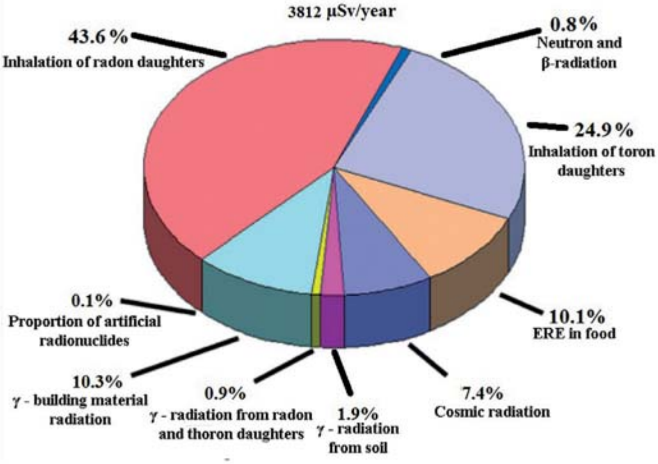


Figure 23. Distribution of the average efficiency of dose loads on the population of settlements, adjacent to the LIRA site

5.2.2. Radiation survey in the outskirts of LIRA facilities

For the first time ever in the world's radio-ecological studies, a comprehensive large-scale radiation survey of the lands and localities in vicinity of underground nuclear explosions site in the immediate vicinity of the developed deposits of natural hydrocarbons was performed. The study was made at the LIRA facilities located in the Karachaganak gas condensate field (KOGCF) in Western Kazakhstan. The main results of the works performed are as follows:

1. The method of survey pits and gamma-spectrometric and radiochemical methods of analysis were used to examine the nature of the depth distribution of artificial radionuclides (^{137}Cs, ^{90}Sr, $^{239+240}$Pu) at the LIRA site, as well as in the floodplain and bed of Berezovka River. The results obtained clearly indicate the presence of radionuclides in the upper layers of soil. None of the 70 surveyed survey pits had significant concentrations of ^{137}Cs or $^{239+240}$Pu at depths below 70 cm. Given that the surveys were carried out in the weakened geologic zones, established by the results of extensive geophysical studies, the hypothesis about the mechanism for the constant inflow of radionuclides to the surface from the cavities of LIRA facilities through the zones of decompactification and fractures in the crust can be considered groundless with confidence.
2. A radiation survey of the Basin of Berezovka River was carried out. It is established that in the bottom sediments of the river upstream (6 km segment) the ^{137}Cs concentrations remain at low (0.5 - 3 Bq / kg) and constant levels. Starting from the southern part of the LIRA site, there is gradual increase in the ^{137}Cs and $^{239+240}$Pu concentrations in the bottom sediments of Berezovka River, which continues until its confluence with Ilek River. The revealed features indicate the mechanism for surface redistribution of radionuclides through their migration with the melt and rainwater from the LIRA site to the floodplain and bed of Berezovka River. The results of the radiation and hydrochemical re-surveys carried out in 2009 confirmed the earlier conclusions that the radiation and ecological situation in the Berezovka River basin is normal and in the period 2001–2009 did not change.
3. A detailed examination of radiological situation at the LIRA facilities was completed as well as on the contract area. Total the area surveyed (site "Central") covered 31 km^2. It is established that the level of radionuclide contamination of the territory does not exceed in general the background values for the region. The distribution of ^{137}Cs in the area was studied. Some anomalies were identified with a high content of it (mainly in the floodplain of Berezovka River). Also we revealed increased concentrations of ^{137}Cs in the upper soil layer (0-10 cm) as moving towards the center section, that is the bed of Berezovka River. These features are a convincing proof for surface redistribution of radionuclides in the direction of Berezovka River.
4. An extensive radiation survey was carried out in the areas surrounding LIRA site within a radius of 20 km. It is established that the average values of the artificial radionuclides concentrations (in 0-30 cm soil layer) throughout the territory remain within the following values: ^{137}Cs - 6.6 Bq/kg, $^{239+240}$Pu - $\leq$ 0.9 Bq/kg, ^{90}Sr

- ≤ 5 Bq/kg. Consequently, the level of radionuclide contamination in the areas (within 20 km) surrounding LIRA site is within the background levels. The level of exposure dose rate also corresponds to the background: 9-15 μR/h. Thus, it was found that the radiation situation at the LIRA site and its vicinity is normal. No signs for any plum or radioactive fallout from the radioactive gas release at the TK-2 (as the eyewitnesses reported) in the entire surveyed area were found. No indication for additional contributions (above the global fallout) from radionuclide contamination at LIRA facilities to the surrounding territories and to the settlements was ever found.

5. In accordance with the recommendations of the International Commission on Radiological Protection in the 16 communities located in the vicinity of LIRA site were surveyed: Akbulak, Aksai, Aksu, Berezovka Bestau, Burlin, Dmitrov, Zhanatalap, Zharsuat, Karakemir, Karachaganak, Oblavskoe, Priuralnoe, Pugachevo, Tungush, Uspenovka. EDR in all the localities were measured (7-15 μR/h), and the levels of soil, water and vegetation (livestock feed - hay, straw) contamination with natural and artificial radionuclides were studied. Levels of radon in the air were determined in the living premises, basements and cellars. Based on the experimental data, there were calculated effective radiation doses to the population. It was found that in general, the radiation situation in the settlements adjacent to LIRA facilities is normal. The greatest contribution to the dose load (43.6%) is due to inhalation of radon and thoron; the contribution from artificial radionuclides is negligible - 0.1%. No impact of LIRA facilities on radioecological situation in the villages has been found.

5.3. Determining the level and extent of deep-seated radioactive contamination

Since its inception, the cavity TK-5 has a special place in the history of LIRA site. Its watering – the source of radiophobia and scary articles in the press. In this regard, the determination of contamination in blocks of rocks, including the borehole and the very cavity was carried out most carefully.

Were conducted geophysical surveys in the control and monitoring boreholes at this LIRA object employing gamma logging (GL). The following results were obtained.

Borehole KN-1

According to gamma-ray survey, the salt dome roof was opened at a depth of 174 m. The sand-clay rocks the natural background levels of gamma-activity of the rocks vary from 1 to 2.3 μR/h and are generally higher than gamma activity in the salt thickness, which varies from 0.4 to 1.5 μR/h. No intervals with anomalous values of gamma activity were revealed.

Borehole KN-2

According to gamma-ray survey, the upper limit of the salt dome is observed at a depth of 172 meters. In terrigenous rocks the level of natural gamma activity varies from 1 to 2.7 μR/h. The sulphate-halogenous rock mass is characterized by low values of natural gamma activity within 0.6-1.4 μR/h. No anomalous values of gamma activity in the borehole section were registered.

Borehole KN-3

According to the curve of the gamma-ray survey, the upper limit of the salt dome is seen indistinct, in totality with thermometry data the salt roof limit may be attributed to a depth of 182 m. The values of natural gamma activity of the terrigenous rock ranges from 0.9 to 2 μR/h, in the sulphate-halogenous rock mass - 0.5-1.3 μR/h. No radioactivity anomaly was observed.

Borehole KN-4

According to gamma-ray survey, the salt roof is observedat a depth of 170 meters. Natural gamma activity of sandy and clay rock ranges from 0.8 to 2.4 μR/h. Natural gamma activity of the sulphate-halogenous rock mass is 0.4-1.5 μR/h. No radioactivity anomaly was observed.

Borehole KN-12

According to gamma-ray survey, the salt roof is observedat a depth of 257 m.

Natural gamma activity (Figure 24) of the rocks in suprasalt terrigenous mass is registered (0-257 m interval) after one, two and three columns, as well as cement and water, and varies from 1.6 μR/h to 5.5 μR/h. The higher values of gamma activity 4-5.5 μR/h emerging at the top of the well cased with several columns, and most likely is due to the large amount of cement in the annulus and do not reflect the lithological features of the section, but only the structure of the boreholes. In the interior of the salt, the level of gamma activity varies from 0.5 μR/h to 5-19 μR/h in certain layers. In general, the section shows that in the clean salts the natural background level of gamma activity is low and varies from 0.5 to 1.2 μR/h. Some thin layers of salt have elevated readings of gamma activity up to 1.5 -2.7 μR/h. Comparing measurements of gamma-ray survey of all previous control - observation wells showed that gamma activity is within the measured background gamma activity of sand and clay rocks and can be explained by the presence of such layers in salt.

To determine the reasons for the presence of zones with high EDR values (up to 19 μR/h), a gamma-ray spectrometric survey at the boreholes KN-4 and KN-12 was carried out. None of the points had Cs-137 in quantities exceeding the detection limit; reached detection limit for cesium-137 comprised 30 Bq/kg. It should be noted that for cesium-137 the value of the minimal specific activity is 10,000 Bq/kg, above which such rocks and materials are subject to radiation safety standards. Additionally it was found that areas with high values of the previously revealed EDR are characterized by high values of natural radionuclide potassium-40 (up to 10,000 Bq/kg). Thus, the results clearly demonstrate the lack of deep-seated radioactive contamination with gamma-emitting radionuclides cesium-137 in the area of the boreholes CK-4 and KN-12.

With that, considering the higher migration abilities of other artificial radionuclides, primarily tritium and strontium-90, it was decided to study further the possible contamination of the rocks in the vicinity of the borehole KN-12 using direct measurements of these radionuclides in the annular space of the well. To determine the possible presence of artificial alpha-and beta-emitting radionuclides in the annular space of the borehole and to check the hydrodynamic connection of the cavity TK-5 with the borehole KN-12 we established a link "stratum-well". For this purpose a casing was perforated in the intervals 875-879 m and 887-892 m with a subsequent stimulation treatment by creating 75% of depression in the zone of perforation at lowering of the liquid level in the shaft to a depth of 669 m. The analyses showed that there are no such artificial radionuclides as tritium, strontium -90, plutonium-

239+240 in the borehole annulus. Certain concentrations of the order of tenths and hundredths of milli-becquerels per litre are associated with their infusion into the borehole as a result of technological operations.

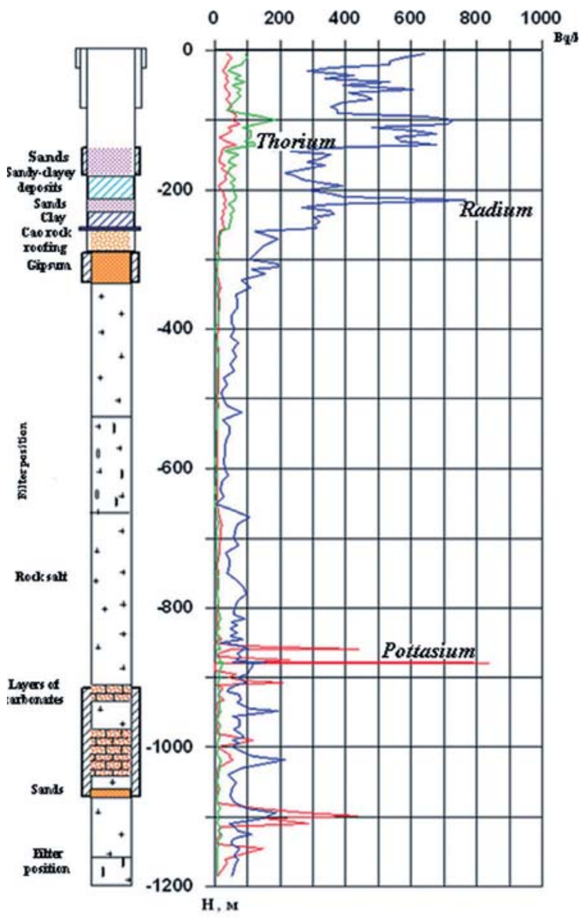


Figure 24. Gamma spectrometry at the borehole KN-12

5.4. Determination of possible proliferation pathways and migration intensity of radioactivity from the cavity TK-5

In the determination of possible pathways and intensity of radioactivity proliferation from the cavity TK-5, a basic issue was a state of the rock mass where the cavity 5RTK is embedded. For the study, the professionals of the IGR NNC RK used vertical seismic profiling and walkaway vertical seismic profiling.

Experimental data showed that the block of the geological environment with the cavity 5 RTK, in general, is a set of zones of sub-vertical and sub-horizontal effects from underground nuclear explosion (UNE). In these areas the following main weak permeable structures are notable (Figure 25):

- the zone of maximal fracturing framing the cavity, with dimensions of about 120-140 meters vertically and in the central section - 100 meters, has a southerly dip.
- linearly elongated sloping zone extending from the cavity toward the surface and sub-horizontal in the direction of the borehole KN12 are most likely interstratial zones formed in brittle rocks (carbonates, anhydrite, etc.). In conjunction with sub-vertical zone of fracturing, they have morphological and, likely, hydrodynamic link with the cavity; so, they can serve as potential channels for radionuclides migration.

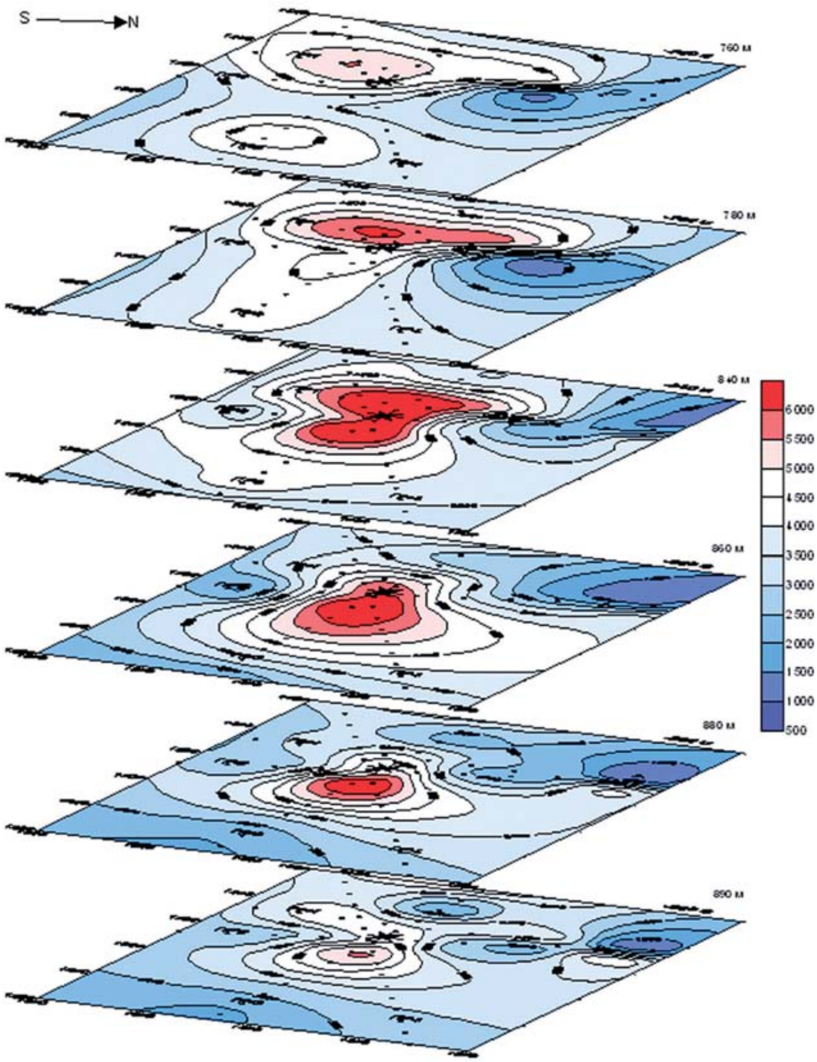


Figure 25. Deconsolidation zone in the cavity TK-5 revealed with the VSP and WVSP methods

Thus, there were not revealed uniform extensive geological zones of decompression, that can serve as a channel for transport of radionuclides into groundwater aquifers and, especially, to the surface. Trying to reveal the most likely pathways for migration, it was taken into account that in addition to permeable geological structures the possible migration pathways is annular space of the boreholes TK-5 and TK-5 "bis", as in the area of salt and aquifers, as a rule, there is no firm grip of a cement with rock. In the intervals of water-saturated rocks, separation of liquid phase of the cement fill takes place with penetration into the reservoir at cementing, and in a salt zone, water from the mortar is involved in the dissolution of salt and a weakening cohesion. So, the contact area of cement stone and rock is the most likely potential migration pass for the radionuclides in these cavities.

Based on the total amount of data obtained from the geophysical research of the cavity TK-5 and a retrospective analysis of geological information, we answered a question about the possibility of draining this cavity. Given an unfavorable condition in the annular space, consisting in extensive destruction zone around the cavity, large cavitation and rich water content in this zone, presence of hydrodynamic connection of the cavity with aquifers of the upper parts of the geological section, set by the unity of the static levels of the Triassic aquifers and water-filled cavity through the hole 5RTK-bis, the draining of the cavity was found to be impossible.

Evacuation of brine from the cavity in these conditions will inevitably be accompanied by a constant influx of water from overlying aquifers with lower salt content than in the brine evacuated. This, in turn, will lead to further dissolution of the cavity walls and an increase in the total amount of liquid radioactive wastes, which contradicts the necessary condition for reducing the radiation threat from LIRA facilities.

5.5. Determining the status of the cavity TK-6

To determine the status of the cavity TK-6, works were carried out in 2002 (Figure 26); this included gauging the wellbore and assessment of the water availability in the well.

Figure 26. Research of the borehole TK-6

As a result of the executed works, the status of the borehole is as follows:

- wellbore is empty to a depth of 900 m, which suggests that the obstruction of rocks is located at the same depth as before, immediately after the rupture. No other borehole collapse during the past period of time has occurred;
- wellbore has no water, which indicates a impermeability of the protective casing annular space, insulating aquifer system of the suprasalt deposits;
- lack of water in the wellbore allows reasonably assuming that there is no water in the cavity, as according to all available data no aquifer system, aquifers and lentils were found in salt-bearing section.

There was studied the crustal block that holds the cavity TK-6 to assess the fracture zones in the vicinity of the cavity and to choose a point for laying additional control and observation well (Figures 27-28).

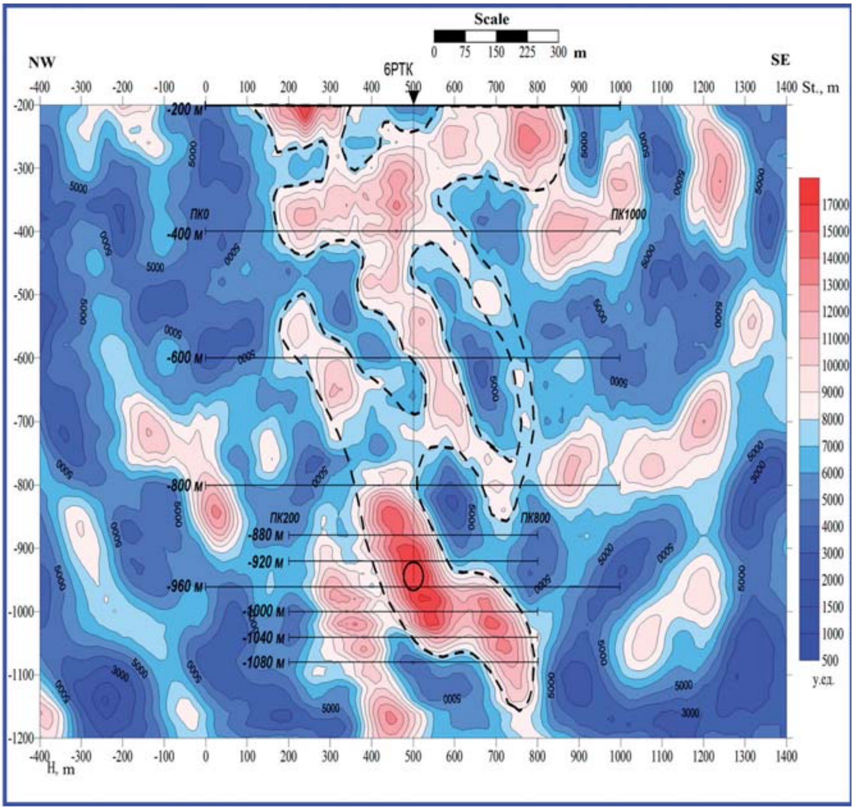


Figure 27. Deconsolidation zone in the vicinity of the cavity TK-6

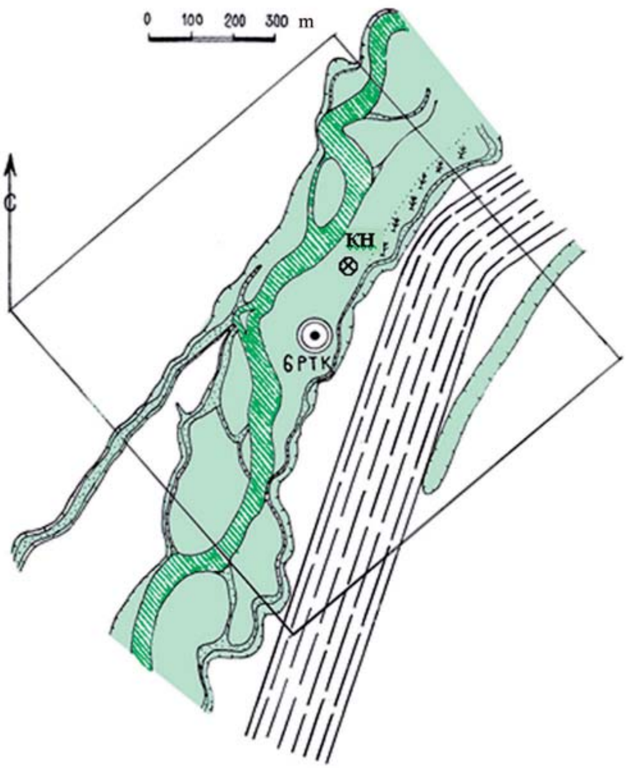


Figure 28. Location of additional observation well in the area of the cavity TK-6

5.6. Developing and implementing of an comprehensive monitoring at LIRA facilities

Based on the research performed by the NNC RK, there was developed and established a scientifically-based comprehensive monitoring system at the LIRA facilities and its vicinity verified and adopted by the Ministry of Ecology of the RK.

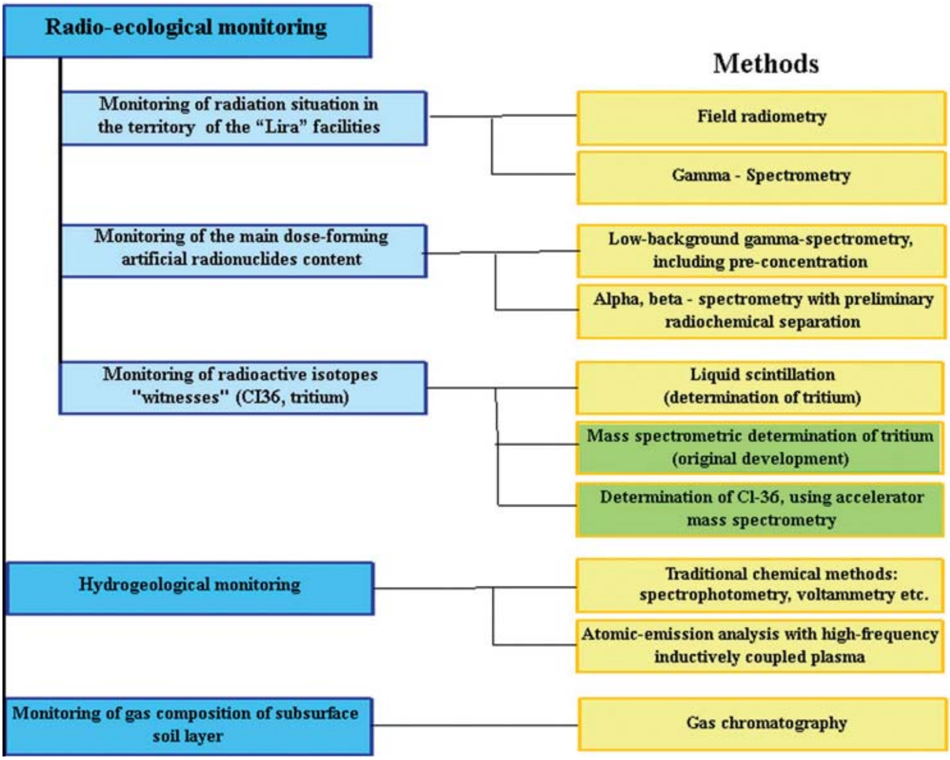


Figure 29. Comprehensive monitoring system of LIRA facilities

The developed monitoring system (Figure 29) is based on the principles of defence in depth, warnings, and forecasts. The difference of the monitoring system from traditional ones in such cases is incorporation of non-dose-forming isotopes - tritium and chlorine-36 - in a series of controlled radionuclides, with the greatest possible mobility in aqueous media, which raises the reliability of the monitoring on a fundamentally higher level of reliability and predictiveness. Any possible situation relating to the determination of radio-ecological state of the observation points at LIRA facilities in our monitoring system is defined by the ratio of the five artificial radionuclides included in the monitoring parameters: tritium, chlorine-36, strontium-90, cesium-137 and plutonium. During the simultaneous measurement of concentrations of these elements at any point of observation one can clearly answer the question about the implication of underground nuclear cavities of LIRA facilities to their appearance in any controlled point. The monitoring system provides two levels of control:

- control of the parameters determining the current radiological situation at LIRA facilities, contracting site and adjacent areas;
- control of the parameters determining the presence, direction and extent of the possible radionuclide migration from underground nuclear cavities.

The purpose of monitoring of the level 1 is assessment of the current radiological situation at the moment and the degree of hazard to personnel and the public on the basis of existing laws, regulations and rules in the field of radiation safety.

Monitoring parameters of the level 2 is not regulated by any regulatory documents and were defined based on the international knowledge about the ways and speciation of radionuclides in natural environments. In order to reveal the radionuclides migration at the earliest stages from the underground cavities, its direction and scales, sensitivity of the isotope determination methods should be extremely high.

In addition to analyzing the content of isotopes associated with underground nuclear explosions, the monitoring parameters of the level 2 is classified as micro- and macro-element composition of groundwater, as its variations show the stability level of the crust, enclosing LIRA facilities and hydrogeological regimen. For this purpose the gas composition is monitored in the subsoil in the zones of geological faults and decompression.

Given the long-term nature of the project and the requirement of independence of the obtained data monitoring from the used instrumental and methodological capacities and the staff, a document was developed: a passport for monitoring of LIRA facilities. The passport regulates all stages of the monitoring and includes a detailed description of the monitoring site locations, sapling procedure and movement of samples and their analysis, organizational structure of the INP NNC RK divisions monitoring, performance quality control procedure. For efficiency and ease of use of the collected information, an electronic version of the monitoring passport has been developed (Figure 30).

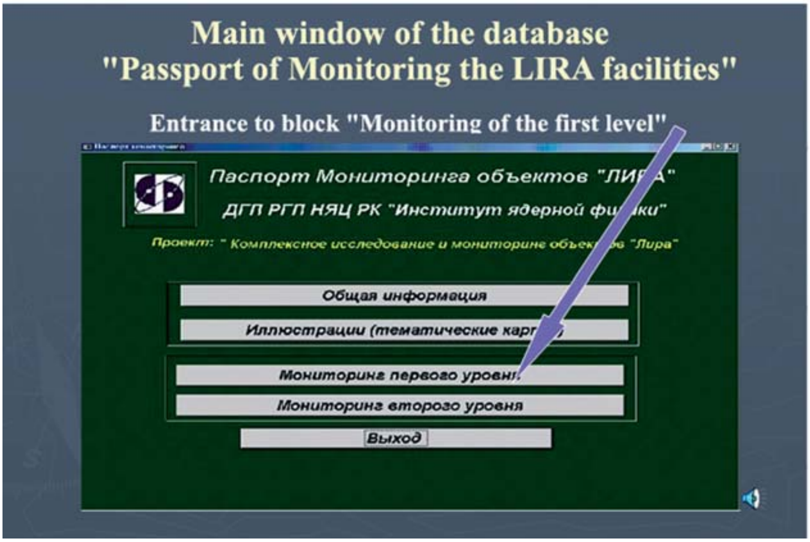


Figure 30. The main window in the database "Passport for Monitoring of LIRA facilities"

The main documents that define the order and amount of monitoring have been approved by the Ministry of Environment and Natural Resources of Kazakhstan, West Kazakhstan territorial environmental agencies, State Standard agencies of the RK. All the monitoring operations are carried out on the basis of the Law "On the use of atomic energy" as per the State license issued by the Committee on Atomic Energy of Kazakhstan and methods certified by the State Standard agencies of the RK. A number of techniques have been developed specifically for the purposes of the Project.

To date, the above-described monitoring system successfully operates on the basis of established infrastructure, including the building and laboratory of the INP NNC RK branch in Aksai town, as well as the laboratory for low-background measurements (Figures 31-32) and other science labs, engineering facilities of the INP and head office of the project management in Almaty. There have been developed, tested and put into practice an instrumental-methodical complex in support of research and other needs of the Project. Lots of inventions developed by the specialists of the NNC RK and used in the monitoring system are protected by patents of the Republic of Kazakhstan.

Figure 31. Laboratory for low-background measurements

Figure 32. Laboratory building of the INP Aksai Branch

6. A NEW MODEL OF THE THREAT DUE TO LIRA FACILITIES

The studies enabled us to obtain systematic information which led to a significant change in the threat model of the LIRA facilities. New understanding about the conditions at LIRA facilities allow us to assert with confidence that:

- at the LIRA site and adjacent areas the radioactive contamination of soil does not exceed the background levels, and there is no contamination in the surface layers deeper than 0.7 meters;
- based on of studies of available for observation points at underground part of the crustal block that enclose LIRA facilities, no proliferation of radioactivity was found from the underground nuclear cavities in the scales that in the near future capable to lead to a significant change in the radioecological situation at KOGCF;
- in terms of radioecology, the cavities TK-5 and TK-6 at the present time are stable with no evidence for proliferation of radionuclides from these cavities to the human environment. Also, no evidence was found that the cavities TK-1 – TK-4 are additional sources of radioactive contamination. Changing the status of underground nuclear cavities is only possible as a result of natural or human-related impacts of the catastrophic nature;
- the most dangerous, and that can rapidly lead to significant deterioration of the radiation situation at KOGCF, mechanism for radionuclides transport from the

underground nuclear cavities to the human environment is the release of radioactivity during emergency depressurization of the wellhead equipment.

7. STRATEGY FOR ELIMINATION OF UNDERGROUND NUCLEAR CAVITIES OF LIRA FACILITIES

The performed comprehensive research and monitoring showed that there is no reason for immediate intervention in the state of underground nuclear cavities, as it was suggested at the beginning of the Project. However, the INP NNC RK, as a specialized organization with the authority provided by the Law "On the use of atomic energy" as per the license of the Atomic Energy RK, all the necessary types of engineering works on the radiation-hazardous facilities of the LIRA site, understands and envisages a significant growing over time risk of technologically-driven changes in the underground nuclear cavities, whose consequences cannot be reliably predicted.

The knowledge we currently gained on the levels and nature of the radioactive contamination at the LIRA site, adjacent territories and in the block of crust that enclose the nuclear cavity led to the conclusion about the possibility of preventing the impact of LIRA facilities on the oil and gas operation at KOGCF, as there is every reason to determine scope of the necessary liquidation operations as executable ones. The essential point here is that the available infrastructure at LIRA facilities allows the liquidation operations.

Since it is impossible to drain the cavity TK-5, the most reasonable scenario of action against it is to establish a regime of long-term monitoring. To further enhance the reliability of early detection of radionuclide migration, taking into account the fact that the most likely pathway for migration is the annulus of the boreholes TK-5 and T-5 "bis", the borehole TK-5 "bis" will be transferred to the category of monitoring through the establishment a communication between the wellbore and an aquifer in Triassic rocks. In case radioactivity is detected in the observed aquifers, the same well will be used for plugging the radioactivity carrier flow, using technologies based on the use of hydro-swelling polymers. The boreholes KN-1 – KN-4 in such situation will also be used for the waterproofing of the aquifers.

Liquidation operations at the cavities TK-1 – TK-4 and TK-6 imply their filling in with highly viscous composite material of sufficient sorption with respect to the main dose-forming radionuclides, preventing the penetration of water into the cavity. The studies have shown that a number of industrial wastes generated during operation of KOGCF, including oil sludges and polluted soils can be used as the fillers. Due to the fact that the engineering implementation of the technology for filling the cavities with composite materials depends on the characteristics and sources of the fillers to be used in the technology, requires a preliminary discussion about the possibility of long-term use of wastes from the nearby businesses as a basis for making a filler.

Since the cavities TK-1 – TK-4 impose additional high risk owing to gas and gas condensate in them (natural gas hazard), a program to eliminate them is a priority. Upon that, corrosion of the process pipeline at LIRA facilities requires making a decision in respect namely of these cavities. In addition, the implementation of the program for filling up the cavities TK-1 – TK-4 with composite material in a binding way requires prior evacuation of the gas condensate from the cavities, its clean-up and disposal of radioactivity. These works are also not possible without the use of KOGCF production facilities.

Such a procedure assures general rapid decrease in the threat of LIRA facilities imposed on the oil and gas operations because even if a limited quantity of specially prepared fillers with a high sorption activity with respect to dose-forming radionuclides gets into each of the cavities, it then will significantly reduce the overall risks at the LIRA facilities.

The liquidation operations cannot be narrowed down to filling the cavities with fillers, as in accordance with applicable law the permission for execution of these works can be obtained only if there are/is available:

- trained and qualified personnel;
- appropriate licenses;
- emergency prevention capacities, ensuring the safety of their execution and the timely elimination of emergency situations;
- instrumentation and methodological capacities for organization of environmental monitoring, process parameters and ensuring the radiation safety.

Monitoring of LIRA facilities will be carried out at all stages of the Project, including those during and after the liquidation operations. The nature of the monitoring will be modified in compliance with the requirements of current realities of the project, ranging from research to industrial and control ones. Scope and parameters of the monitoring upon that will be determined by taking into account the new state of LIRA facilities.

"ЛИРА" НЫСАНДАРЫН КЕШЕНДІ ЗЕРТТЕУ ЖӘНЕ МОНИТОРИНГІЛЕУ" ЖОБАСЫНЫҢ ДАМУ СТРАТЕГИЯСЫ (1998–2010 жж. жұмыс нәтижелері негізінде)

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Мақалада ЛИРА нысандарының радиоэкологиялық мәртебесін бағалау, нысандағы тереңдік радиоактивті ластану деңгейі мен көлемін анықтау, сондай-ақ іргелес аумақтар мен елді мекендердің жерүсті радиоактивті ластануы бойынша ҚР ҰЯО жүргізілген зерттеулерге шолу жасалған. ЛИРА нысандары мен іргелес аумақтардың әзірленген ғылыми негізделген кешенді мониторинг жүйесінің негізгі принциптері ұсынылған. ЛИРА нысандары мен радиациялық қауіпсіздікті қамтамасыз ету концепциясына байланысты қауіп-қатер үлгісінің дамуы қарастырылған. ЛИРА нысандарының жерасты ядролық қуыстарын жою бойынша жұмыстар стратегиясының негізі жасалды.

СТРАТЕГИЯ РАЗВИТИЯ ПРОЕКТА "КОМПЛЕКСНОЕ ИССЛЕДОВАНИЕ И МОНИТОРИНГ ОБЪЕКТОВ "ЛИРА" (на основании результатов работ 1998–2010 гг.)

Кадыржанов К.К., Лукашенко С.Н., Солодухин В.П., Агеева Т.И., Глущенко В.Н.,. Силачев И.Ю, Николаев И.М., Позняк В.Л., Новозенко В.А., Кияткина Н.Г., Глущенко Г.М., Матиенко Л.Д.

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В статье проведен обзор исследований, проведенных НЯЦ РК, по оценке радиоэкологического статуса объектов ЛИРА, определению уровня и масштабов глубинного радиоактивного загрязнения на объекте, а также поверхностного радиоактивного загрязнения прилегающих территорий и населенных пунктов. Приведены основные принципы разработанной научно обоснованной комплексной системы мониторинга объектов ЛИРА и прилегающих территорий. Рассмотрено развитие модели угрозы в связи с объектами ЛИРА и концепции обеспечения радиационной безопасности. Обоснована стратегия работ по ликвидации подземных ядерных полостей объектов ЛИРА.

PART: ENSURING THE WORK SAFETY ON THE STS

УДК 577.4:553.9:504.064:621.039.9:539.16

RADIOECOLOGICAL CONDITIONS AT THE KARAZHYRA COAL DEPOSIT

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The results of long-term radio-ecological studies at the territory of Karazhyra coal deposit at the Balapan site of former Semipalatinsk Test Site (STS) are presented. It has been revealed that contents of artificial radionuclides on a day surface in the area of deposit area were mainly formed by global fallouts. Radiological parameters and concentrations of radionuclides in soil and air do not constitute a danger for the coal deposit products. No radioactive contamination of equipment, vehicles or staff premises is found.

Recommendations on further radiation control and radioecological monitoring to provide safety of deposit development and obtain necessary data for prediction of development of radioecological situation in the deposit area are given.

Keywords: deposit, Balapan site, hydrogeology, radionuclide contamination, monitoring, underground nuclear explosions.

INTRODUCTION

With the Presidential Decree No 409 dated August 29, 1991 "On Closing of the Semipalatinsk Test Site" a new stage in the use of the territory and subsurface resources began: exploration and mining operations. The first such deposit was the Karazhyra coal deposit. In 1996 the State Commission for Mineral Reserves under the Kazakhstan's Ministry of Geology and Subsoil Protection assessed the mineral reserves of the deposit in the amount of 1.2 billion ton. Construction of a pilot coal pit was started. It was preceded by a big work on complex geological, hydrogeological and engineering-geological survey with simultaneous works on the radiation and environmental assessment of deposit area with a view to provide radiation safety of personnel during the deposit exploration and development operations. This paper presents the data on the long-term radiological studies carried out by INSE NC RK at the territory of Karazhyra coal deposit.

Karazhyra deposit is located on the territory of Balapan site of former Semipalatinsk Test Site (Figure 1).

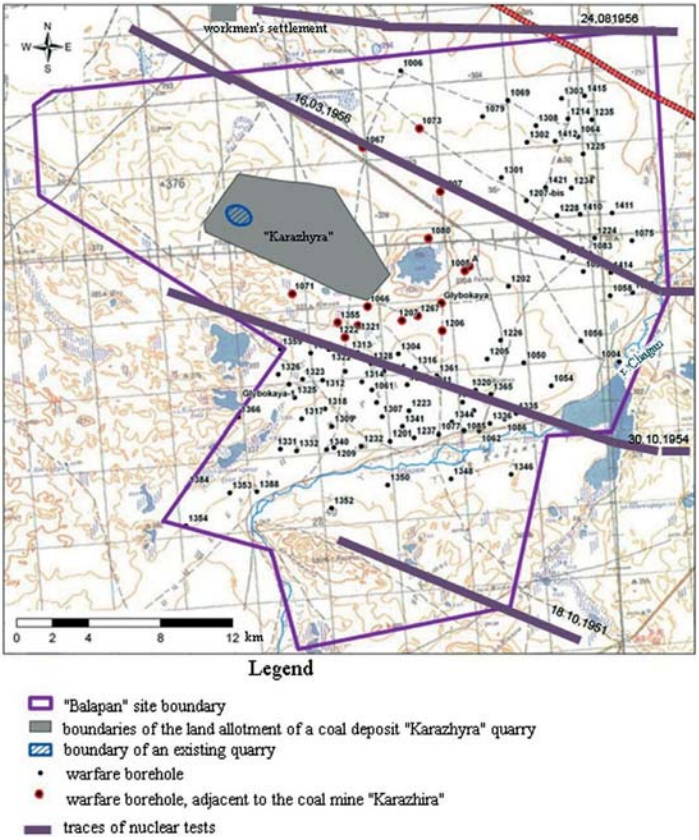


Figure 1. Balapan Site. Location of the Karazhyra deposit

106 underground explosions were conducted in "warfare" boreholes on the territory of Balapan site [1]. The data on the "warfare" boreholes nearest to the deposit are summarized in Table 1.

Table 1.

Summary data on the "warfare" boreholes

##	Well No.	Testing date	Well depth, m	Explosion yeld, kton	Distance to the deposit land limit, km	Distance to the pit, km
1	**1005**	16.10.74	350	43	4.3	12.3
2	**1007**	10.02.72	454	16	5.1	10.7
3	**1066**	23.07.73	655	212	0.4	8.2
4	**1067**	25.12.75	400	59	2.8	7.3
5	**1071**	25.04.80	332	2 – ≤ 20	1.3	4.7
6	**1073**	12.11.77	306	15	5.8	10.6
7	**1080**	29.06.77	504	9	3.2	9.9

##	Well No.	Testing date	Well depth, m	Explosion yeld, kton	Distance to the deposit land limit, km	Distance to the pit, km
8	**1206**	29.10.75	599	90	4.4	12.3
9	**1207**	31.05.74	No data	104	2.2	10.1
10	**1222**	29.11.78	550	100	2.4	8.4
11	**1267**	20.09.73	373	15	2.9	10.7
12	**1321**	04.07.82	595	136	1.5	8.3
13	**1355**	13.12.87	600	130	1.7	7.5
14	**deep**	23.12.79	1250	70	3.8	11.6
15	**A**	30.11.77	202	4	4.5	12.4

According to the above data, the "warfare" boreholes nearest to the land allotment borders are located 0.4 – 5.8 km away and 4.7 – 12.4 km away from the pit to be developed. The issue of the rate of hazard from the "warfare" boreholes is still open. Among the problematic issues there stand out two key problems: the first one is related to a possible outflow of ground water contaminated with induced radionuclides to the coal open-pit to be developed. The second problem relates to the dangerous aftermaths of underground gasification processes in the rocks enclosing central UNE zones at the Balapan site [2].

The conditions of test site and mining operations and the relative closeness of wells in which nuclear explosive blasts had been conducted therefore require radiation safety and radiation protection assurance to be implemented for coal miners (open-pit personnel.)

Pursuant to the Law of the Republic of Kazakhstan 93-1 dated April 14, 1997 "On the Use of Atomic Energy", all kinds of activity at nuclear explosion sites should be regarded as the activity in the field of use of atomic energy and shall therefore be subject to licensing. Consequently, one of the basic conditions for authorized activities at the UNE territory for all enterprises is to obtain license at the Committee for Nuclear Energy of the Republic of Kazakhstan for particular kinds of activities and ensure protection of public health and environment from harmful ionizing radiation. Generally, special enterprises (institutions) have been engaged to perform radio-ecological researches and monitoring at nuclear explosion sites. One of such institutions is INSE NC RK.

1. GENERAL INFORMATION ON THE DEPOSIT

1.1. Physiographic description of area

Administratively, the operations area is a part of Zhanasemei and Abrali districts of East Kazakhstan Oblast with the city Ust-Kamenogorsk as an administrative center. The territory is connected with the city of Semipalatinsk by a highway (90 km) changing into an earth road (40 km). Balapan settlement is located north of the site. There is a railroad going from Kurchatov to the open-pit.

In the northern and eastern parts of the territory, there prevails a hilly plain with 12–20 m elevations. South-westward, the relief changes to Kazakh Upland characterized by close shallow dissection with 200–320 m absolute heights and 30–80 m local differences in elevation. The hillocky area is generally divided into separate massifs with wide valleys and basins and typical uplifts and ridges with stony surface. In the depressions between ridges and hills there are shallow swamped lakes and solonchaks and on the surface of quaternary deposits, in the midst of plain, frequent sor-deflation declines and depressions. In the areas of Neocene and Paleocene clay outcrop, on surface there are heaving hummocks of 1m height and 2-3m in diameter.

The lakes are saline and biter, non-perennial. The biggest of them are Karazhireksor, Kishkeneksor and Kayaksu located at the eastern borders of the site and forming a typical deep isometric hollow surface of alluvial terrace in the midst of the plain. The hydrographic network is poorly developed. The area includes several dry *sais* which are the major watercourses in spring and rainy periods. All of them fall into the local lakes. South of the site, 4-5 km parallel to its boundary, the River Shagan flows, drying up in summer. It is the only water artery in the area and only on some of its sections it has a low-discharge flow.

The soil is grey-chestnut, rubbly, often saline and only sometimes, in water-flooded ravines and valleys, chernozem. The vegetation is scanty with the prevalent mixed grass feather, grass fescue and steppe herbs. Elm and dog rose shrubs grow in *sais* and watercourse valleys.

The population of the area is concentrated in Balapan settlement and at present is engaged in the development of Karazhyra deposit. Potable water is delivered to the citizens by the conduit laid from the Irtysh River in the area of the city of Kurchatov to Balapan settlement.

Climate in the area is extremely continental with average annual air temperature of not higher than +3.5ºC. The absolute maximum of temperature is +40ºC and minimum is –40ºC. The average monthly temperatures in July and January are +19ºC and –16ºC, respectively. The average daily temperature is above zero in the period from the 4th to 9th April; the frost-free period lasts about 200 days. The last spring frosts last until May, 20 and the first autumn frosts begin from the 10th to 15th September. Winter is long, cold and low-snow; the average snow cover is 25-35 cm; the snow cover is steady for 140-150 days. In spring, the temperature varies from 8ºC to 19ºC, and the snow cover disappears in the first half of April. Summer is hot and dry, the average temperature is 25-27ºC, rainfalls are rare, short and showery. Autumn in the beginning is warm and clear and at the end – cold and cloudy; snowfalls begin at the end of October.

During the whole year, winds blow in eastern and western directions at mainly 3-4.5 m/s velocities, and sometimes reach storm force causing dust or snow storms.

1.2. Geological structure of the deposit

Structurally, the Karazhyra coal deposit is a wedge-shaped Jurassic-aged graben of 13 km length and 3.5-5.0 km width. The deposit area is located in the zone of Chingiz-Terbagatai megaanticlinorium and Irtysh-Zaisan megasdinclinorium joint. The area under consideration is broken down by big faults to several blocks. According to the data of detailed exploration of the deposit, the geological structure is composed by different-age sedimentary, effusive and intrusive rocks which, according to the level of folding, are subdivided into two structural levels: lower – Paleozoic and upper – Mesozoic- Cenozoic. (J, P, N, Q).

The following stratigraphical units are distinguished among Paleozoic formations:

- Famennian-Tournaisian stages – Karobai suite (D_3-C_1kr_1);
- Tournaissian stage – Koyandin suite (D_1kn);

- Viseian stage, lower substage – lower and middle Kokon suites ($C_1кк_1$, $C_1кк_2$);
- Viseian stage, middle division – Bokon suite ($C_2вк$); and
- Viseian stage, upper division – Maityuben suite (C_3mt).

Paleozoic formations are represented by coarse and fine sandstone, silicified siltstone, conglomerates, coal-clay slate and effusive rocks of basic and intermediate composition. Outcrops of these sediments can be seen along the tectonic fault lines in the south-east and south-west of the area.

The following stratigraphical units are distinguished within the Mesozoic-Cenozoic platform mantle:

- Jurassic suite – lower member (J_1).
- Paleocene system – Eocene (P_2).
- Neocene system – Miocene-Kalkaman (Aral) suite;
  - Miocene- Pliocene (Pavlodar) $N_{1-2}pv$) suite.
- Quaternary system:
  - Middle-upper members (Q_{II-III});
  - Upper-contemporary members (Q_{III-IV});
  - Contemporary member (Q_{IV}).

Lower Jurassic sediments within the graben compose the above-coal, coal-bearing and under-coal strata.

The under-coal stratum (J_1pug) is composed by siltstone, argillite, sandstone with coal layers and small pebble interlayers. The stratum thickness is 90-140 m.

The coal-bearing stratum (J_1ug) is composed by siltstone, argillite, sandstone and high coal seams. The stratum thickness is 180-300 m.

The above-coal stratum (J_1nug) is composed by sandstone, comglomerates, gravel-stone, siltstone with coal and coaly rock layers. The position of Lower Jurassic formations is almost horizontal (the dip angle is 3-5^0, rarely 10^0) and only on tectonic faults the dip angle is up to 45-80^0.

Eocene sediments (P_2) are presented by clay of various color with lenses and layers of sand, seldom gravel and pebblestone standing out as small-area patches of 10-15 m-thick. The clay of Kalkaman suite $N_1кlк$) is not everywhere developed; its thickness is not always 10-15 m, sometimes reaching 40 m. The Pavlodar suite sediments $N_{1-2}pv$) are developed in the eastern and northern parts of the section and are represented by dense and strong sand-stone and clay marl of typical red, brown and green-brown color; lenses and marl nodules, carbonate and ferriferous-manganese nodules, gypsum inclusions often occur; lenses and interlayers of sand, rarely gravel sometimes occur; the thickness of suite is 5-10 m, and sometimes 15 m.

Middle-upper-quaternary alluvial and alluvial-proalluvial sediments (Q_{II-III}) compose the second above-floodplain terrace of the River Shagan. The sediments are represented by mainly alternating sands, loamy sands and gravel-pebble formations. Sometimes loam and sandy clay layers are present. The thickness of sediments is 4-8 m, rarely reaching 15 m.

Upper quaternary and contemporary formations (Q_{III-IV}) in the deposit area include diluvial and diluvial-proluvial sediments of sandy clay with landwaste, gravel and rarely pebbles. The thickness of sediments is 0.5-2.0 m and rarely 2.8-3.5 m.

Contemporary sediments are widespread in floodplains, river-beds and in the bottom of lakes. The sediments are developed in the western part of deposit (Graphical Appendix 2) and are represented by clayey sand, sandy loam, humic loam and gravel-pebble deposits and inequigranular sand.

In the area under study, the intrusive sediments crop out in the south-west of the deposit, and in the remaining area they are uncovered by boreholes. The sediments are represented by two complexes:

Early Carboniferous (Saur C_1s) and Later Carboniferous (Argibai ɣC_3a);

- The first stage of Saur complex (ργ C_3s) is represented by amphibolic gabbro and gabbro-diorites, which sometimes change to amphibole-pyroxene gabbro or diorites and quartz diorites;
- The second stage of Saur complex (ργ C_1s) incorporation is represented by plagiogranites;
- Intrusions of Argibai complex (ɣC_3a) are developed in the most south-easterly point of deposit and are represented by green gabbro-diabases changing to diabases and diabase porphyrites.

The superimposed wedge-shaped graben representing the Karazhyra deposit in the north-east and south-west is bound by thrust faults. In the north-east it is bound by the upthrow fault (Chinrau fault). The fault zone dips north-east at an angle 50-80^0, and the amplitude is more than 500 m. In the south-west the graben is bound by the upthrow thrust (Karazhyra fault) along which an overlapped-thrust structure had formed. The upthrow fault dip is 2.3 south-west at an angle 45-80^0, and the amplitude is over 500 m. Here the Paleozoic intrusive formations are thrust over the coal-bearing Jurassic stratum. The remaining upthrow faults are shorter in length (1.5-4.0 km) and the displacement is from 20-60 m to 100-200 m. All dislocations are accompanied by large shear zones where the rocks had transformed to breccias or mylonites. [3].

1.3. Hydrography and hydrogeology of the area

Hydrogeologically, the Karazhyra graben is a small sub-artesian basin the basic ground water supply in which is confined to the Lower Jurassic sediments. The overlying Cretaceous-Paleocene and Neocene formations are regarded as a confining layer preventing, due to mainly clay composition, the ground and surface water from flowing to the underlying horizons.

Quaternary formations occupying a considerable area are slightly watered; and ground water in them is locally distributed. The basic water bearing complex within the Karazhyra deposit is represented by Lower Jurassic water-bearing complex. All major inflow volumes to the open-pit are due to this complex.

In plan, the Lower Jurassic water-bearing complex is distributed throughout the deposit area. The northern and southern boundaries pass along the regional fault zones, and the western and eastern boundaries had formed far beyond the deposit.

The recharge conditions of water-bearing complex of Lower Jurassic sediments are not favorable due to the wide-spread occurrence of Neocene clay and Quaternary loam and presence of low-permeable loam on its section. Low slopes of ground water table, low filtration factors, difficult recharge and lack of sufficient storage capacity are not favorable for the formation of sweet ground water supply of potable quality to this area.

The lowest mineralized water with 5 g/lm^3 total mineralization is widespread in the area of local supply and active water exchange. Some sections of such water propagation are found in the watershed area between the deposit and lake basins in the south. The water is sulfate-chloride, calcium-sodium. The next zone of groundwater with 5-10 g/dm^3 mineralization separates as a narrow strip the Karazhrek-Kishkenesor lake basin from the Koyaksu lake basin and Karazhyra deposit. The water is sulfate-chloride-magnesium, calcium sodium, and chloride-sulfate, calcium-sodium. A zone of groundwater with more than 50 g/dm^3 mineralization is distinguished in the lake basins (Karazhrek, Kishkenesor). The water is chloride magnesium-sodium. The next zone is the groundwater with 35-50 g/dm^3 mineralization; the water is chloride and calcium-sodium-magnesium. In the remaining territory, the water has 10-35 g/dm^3 mineralization. Similar zonality exists in the north of the area.

A considerable part of the deposit area has underground water with 25-50 g/dm^3 mineralization, and on the adjacent sections water with 10-35 g/dm^3 mineralization is widely spread. Here, water is sulfate-chloride, magnesium-sodium. In the Kayaksu lake basin, zones with 35-50 and more than 50 g/dm^3 mineralization are present.

The lowest water mineralization, 6.5-9.4 g/dm^3, within the deposit is found in its south-western part, closer to the conjectural recharge area, and the highest mineralization (30 g/dm^3 and higher) – south-east of the operating pit. Water with higher than 40 g/dm^3 mineralization is found in the fault zone round borehole 501.

On the whole, the water-bearing complex of Lower Jurassic sediments in the deposit area includes water with 9.4-55.5 g/dm^3 mineralization. Chemically, the water is chloride, sulfate-chloride, magnesium-sodium. The general movement of water is from south-west and west to north and north-west in the direction of the River Irtysh valley. Part of underground water is discharged into the natural lake basins of Karazhrek, Kayaksu, etc. [3].

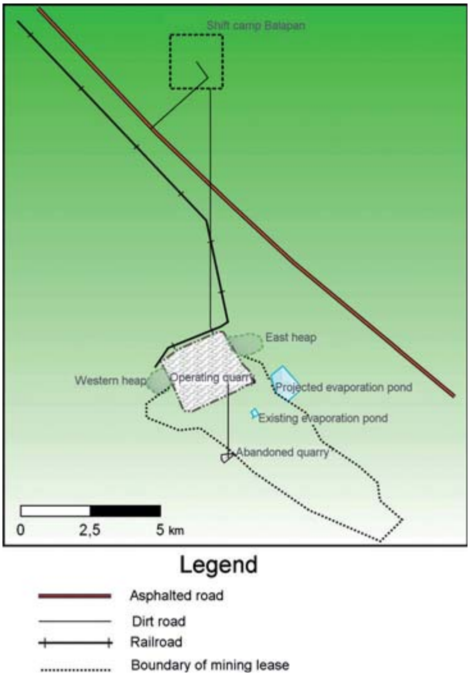
1.4. The peculiarities of the deposit development

The lease area of Karazhyra deposit is 21.4 km^2, and the approved coal reserves are 1.2 billion tons. The excavation method is open pit, partially using drilling-and-blasting for scarifying. The development method is transporter, with transportation of overburden to the external and internal dumps. Production benches are made by H-95 excavators of DEMAG company (Germany). Overburden benches are made by EKG-5A and EKG-8I excavator-mining power shovels, coal and overburden are transported in BelAZ-75489, BelAZ-75485 and BelAZ-75405 dump trucks. Bulldozers with T-130 and T-170 tractors are used for subsidiary works. Stripping operations sometimes involve drilling-and-blasting using 3SBSh-200-60 drill rigs (Figure 2 a).

Coal from the open pit is transported to the point of reloading to railway cars or to a coal storage located at the platform of technical complex (Figure 2 b).

At present, at the open pit an open drainage system is arranged which includes two pump stations and water pipeline. The volume of pumped off water is on the average 294-574 thou.m^3/year. Drainage water is discharged by pipeline to an evaporation pond.

Total there are about 500 workers at the open pit; the regime of work is rotational, with 200 persons in a shift team.



a) b)

Figure 2. a) General view of the open pit, b) Basic elements of Karazhyra deposit infrastructure

2. FACTORS AND MECHANISMS FOR FORMATION OF RADIOLOGICAL SITUATION

At the most general level, the radiological situation on any territory can be presented as a superposition of two components:

1. Natural environmental radioactivity.
2. Environment pollution by artificial radionuclides.

2.1. Natural environmental radioactivity

The natural radiation sources are *cosmic radiation and natural radioactive substances* spread on the surface and in the Earth crust.

2.1.1. Radioactivity of rocks

The average specific activity values for natural radionuclides in rocks according to the literatures data [4] are presented in Table 2 below.

Table 2.

Specific activity of natural radionuclides in rocks

Rock	Specific activity, Bq/kg		
	^{238}U	^{232}Th	^{40}K
Magmatic			
Acidic	60	80	1000
Medium	20	30	700
Basic	10	10	240
Ultrabasic	0.4	25	150
Sedimentary			
Limestone	30	7	90
Sandstone	19	10	370
Clay shale	44	45	700
Mineral coal	-	30	276

The highest content of artificial radionuclides is found in potassium-rich igneous rocks of acidic and alkaline composition. The highest radioactivity among sedimentary rocks is found in clay and clay shale. The lowest radioactivity is found in chemically pure and organogenous sediments, such as rock salt, gypsum, limestone, dolomite, quart sand, siliceous schist and gem jade.

A major soil source of radioactive elements is soil-forming rocks. The specific activity of basic soil types [4] is presented in Table 3.

Table 3.

Specific activity of artificial radionuclides in soil

Basic soil types	Specific activity, Bq/kg		
	^{238}U	^{232}Th	^{40}K
Gray	31	48	670
Gray-cynnamon	28	41	700
Chestnut	27	37	550
Black	22	36	410
Gray forest	18	27	370
Sod-podzolic	15	22	300
Podzolic	9	12	150
Peaty	6	6	90

Soil formed on acidic magmatic rocks is to some extent enriched with radioactive elements (uranium, radium, thorium, and potassium), and soil formed on basic and ultrabasic rocks has low concentration of them. Almost everywhere, clay soil has higher concentration of radioisotopes than sandy soil.

2.2. Environmental contamination with artificial radionuclides

The sources of Earth surface contamination with artificial radionuclides are quite numerous and various. These are the accident ejections from nuclear power stations, nuclear weapon tests, nuclear explosions for peaceful purposes, nuclear research reactors, pollutions of seas by nuclear-powered ships, radioactive waste, etc.

In the territory under consideration, due to the specificity of its geographical position, the contamination with artificial (technogenic) radionuclides should first of all be stipulated by nuclear tests conducted at STS with formation of the following basic radionuclides :

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

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

The basic potential sources of pollution in the territory under study are the aftermaths of both the remote fallouts of nuclear surface explosions performed in 50s-60s and the result of nearby fallouts due to release of radioactive gases and aerosols during downhole experiments at the Balapan site.

2.2.1. Contamination of day surface soil due to nuclear explosions

2.2.1.1. Atmospheric radioactive fallouts

Ground nuclear tests have led to high radioactive contamination of large territories, having formed radioactive traces extending for hundreds of kilometers from the explosion epicenter.

At the time of conducting atmospheric tests, the radiological situation in the areas adjoining the nuclear testing facilities was mainly formed by 11 previous ground tests because other tests were conducted in the regime of maximum deposition of nuclear explosion products directly within the TEST SITEs [5]. Having reviewed the available information, 3 ground tests that could cause radioactive contamination at the Karazhyra deposit area have been identified (Table 4).

Table 4.

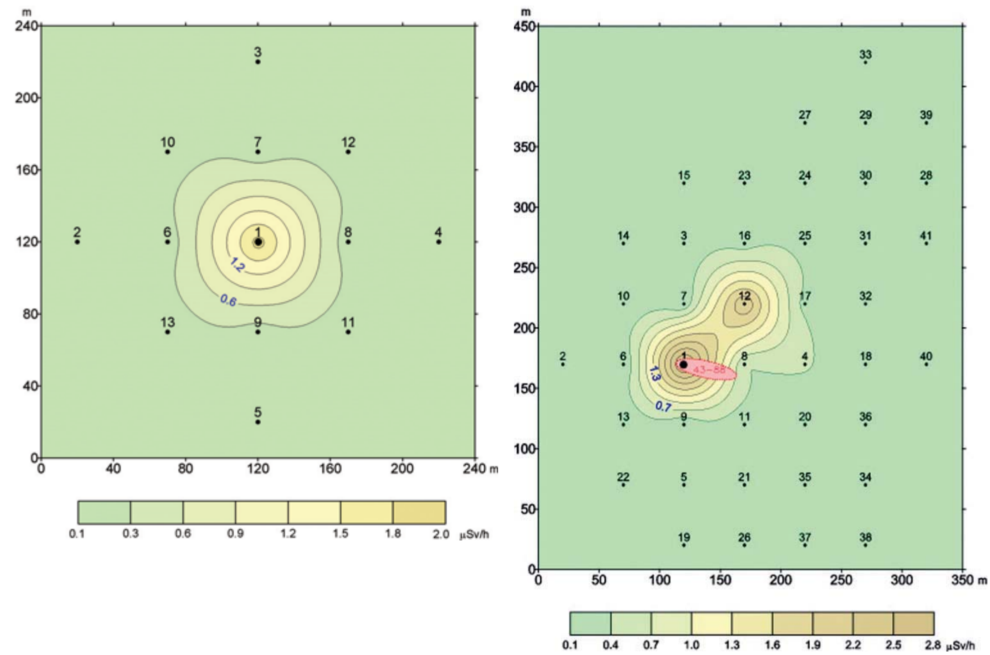
Ground nuclear tests with potential impact on radioactive contamination in the studied area

#	Testing date [5]	Testing site (ground) [5]	Test purpose [5]	Energy release, kton TNT [5]	Explosion altitude, m [5]	Average wind direction, grad [5]
1	30.10.54	P-3	NWD	10	Aircraft release with explosion at 50 m (55 m)	
2	16.03.56	P-2	NWD	14 (13.2)	0.4	
3	18.10.51	P-5	NWD	7	0	
NWD – nuclear weapons development						

Thus, 3 ground tests could cause radioactive contamination in the area of the Karazhyra deposit.

2.2.1.2 Local contamination of epicenter zones of UNE at Balapan site

The deposit is located offside the intensive radioactive traces of ^{137}Cs and ^{90}Sr. However, point sources of contamination have been found around the mouths of the nearby wells [6]. Local contamination spots in UNE epicenter zones at the Balapan site have been formed due to mainly nearby fallouts caused by release of radioactive gases and aerosols during nuclear tests in "warfare" boreholes. Such effects occur in case of partly contained explosions (56 wells) or emergency radiation situations (wells 1007, 1204, 1069, 1301). As an illustration, Figure 2 shows the nature of EDR distribution round the mouths of two "warfare" boreholes.



well 1077 well 1080

Figure 3. Distribution of EDR in wells 1077 and 1080

A significant role in the creation of radiological situation in the testsite area belongs to the excavation explosion in the well 1004 made at construction of artificial storage in 1965 (the so-called "Atomic" lake). The explosion had produced and dispersed long-lived radionuclides: $^{239+240}Pu$ – 8.5 Cu; ^{137}Cs – 800 Cu; ^{60}Co – 80 Cu; ^{152}Eu – 120 Cu; ^{90}Sr – 400 Cu; ^{3}H– $4*10^5$ Cu. In the rubblized zone, up to 40% of produced radionuclides fell out. The cloud formation during the explosion in the well 1004 and radioactive trace occurred at anomalous distribution of temperature and wind in depth. In addition to the unusual distribution of temperature in depth, there occurred a considerable turn of wind in the direction of increasing height (almost 100% to the right within the maximum height of cloud rise). The combination of these factors caused formation of local radioactive trace of complicated configuration.

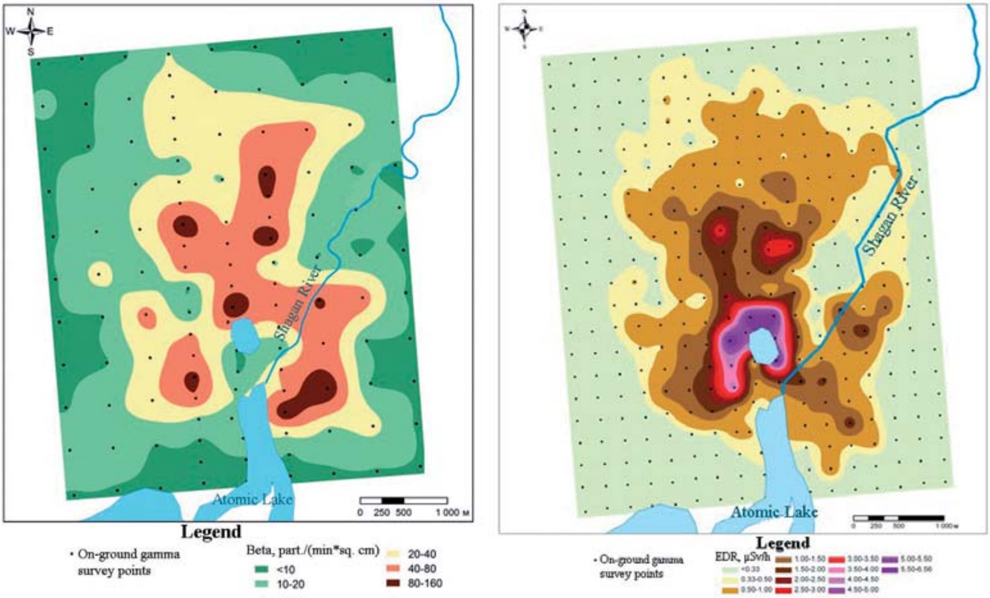
Thus, radioactive aerosols in the layer at 0 to 750 m height moved at 330° azimuth and caused contamination of ground due to the fallouts from the base surge. The lower part of the atomic cloud, being in the layer of 750 m to 2500 m, formed the "northern branch" of the trace with 40-47° azimuth axis, and its upper part raising above 2,500 m and moving at 70° azimuth formed the "southern branch" of the trace.

The explosion had caused high contamination of the surrounding area. Now, the exposure dose rate on the funnel crest, which has been filled with water, is up to 0.1 mSv/hour. According to the detailed radioecological survey of the site in the area of "Atomic" lake at 20 km^2 area, the maximum values of radiation parameters are:

- EDR– 6.56 mSv/hour (EDR values exceed the background values in 169 points);
- The flux density of surface alpha emission is 4.4 particles/cm^2*min;
- The flux density of surface beta emission is 160 particles/cm^2*min.

The flux density of surface beta emission was measured in the points every 500 m, and in the locations where EDR was more than 100 mSv/hour the measurements were made every 250 m (Figure 4).

According to our results, virtually on the whole surveyed territory the contamination with ^{137}Cs and ^{90}Sr exceeds the background of global fallouts.



a) b)

Figure 4. Density distribution of surface contamination with β-particles and equivalent doze rates in the area of "Atomic" lake

All soil samples measured for $^{239+240}$Pu content showed excess over global fallout background for hundreds of times.

2.2.1.3. Contamination of day surface of soil due to global atmospheric fallouts

Now virtually in any place of our planet the radiation contamination of environment can be identified due to various nuclear tests and accidents at nuclear power plants.

The thing is that during atmospheric nuclear tests a great portion of radioactive products is released to the stratosphere. Radioactive aerosols of microscopic size (~$4*10^{-5}$ cm) as a component of radioactive cloud remain in the stratosphere from several months to several years, and winds carry over this cloud throughout the Earth (stratospheric transport).

Artificial radionuclides from the atmosphere together with rainfalls and dry fallouts get to the surface. Density of such so-called global fallouts depends on the geographic latitude of terrain, time passing after the release of artificial radionuclides (IRD) to the atmosphere, season and meteorological factors [6].

After signing the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, the radioactivity of the atmosphere has been progressively decreasing and by now it is hundreds of times lower. A short-term increase in the radioactive contamination of earth atmosphere during the last decade was recorded in 1986 due to the Chernobyl NNP accident [1].

According to the calculations [2], the specific activity of global fallouts in 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.

2.2.1.4. Mechanical transport of contaminated soil

The above-described fields and spots of radioactive contamination are sources of possible further transport of contamination by people or machinery by access roads, developed territories, etc. Such mechanism of propagation can hardly play a significant role in the formation of the picture of radionuclide contamination of the territory; it can rather be a concern to individual persons exposed to such contamination. Hence, in the validation of the types and quantities of activities for the radiation monitoring a possibility of transport of radionuclide-contaminated soil from nuclear test areas to the coal mine territory and further propagation by transport vehicles has been taken into consideration.

2.2.2. Ground water contamination with artificial radionuclides

The mechanism of radioactive ground water contamination with UNE products is described in detail in Ref. [9].

A major issue of concern regarding the radiation safety of works at the Karazhyra deposit is a probability that the ground water contaminated by the radioactive products of underground nuclear explosions gets to the borders of the deposit. A basic precondition of such probability is the process of cone depression growth. The point is that under the impact of pit sump a drainage cone forms. The cone may finally affect the areas where the "warfare" boreholes are located. The formation of drainage cone is accompanied by an increase in the piezometric surface slope of fissure water that may cause equivalent intensification of processes of groundwater migration and movement to the open-cut. Now the cone radius is 9 km. Herewith the depth of drainage is more than 50 m. Now the eastern front is located a few meters from the subartesian groundwater basin with high radionuclide concentrations.

The groundwater contaminated with artificial radionuclides can get to the deposit borders from UNE locations at the Balapan site. The results of the research show that high concentrations of ^{137}Cs and ^{90}Sr in the groundwater are present only close to UNE epicenter zones; with distance from the mouth of "warfare" boreholes to 300 m the radionuclide concentration decreases to mBq/kg. Hence, any peculiarities in the mode of ^{137}Cs and ^{90}Sr propagation have not been so far recorded due to their low concentration. However, ^{3}H concentration in the groundwater varies within a wide range from a minimum detectable activity, 7 Bq/kg, to the maximum values higher than 4 million Bq/kg. Thus, tritium is a basic radioactive contaminant of groundwater at this site. It should be taken into consideration that tritium is a component of water and is not sorbed by rocks. Hence, with growth of depression cone the tritium-contaminated groundwater may quite shortly get into the deposit water.

It is worth mentioning that Karazhyra deposit is structurally a wedge-shaped Jurassic graben of 13 km length situated between Chinrau and Karazhira faults. In this situation, the basic possible ways for the contaminated water to get into the mine tunnels are the zones affected by these faults. Hence it is not impossible that in the future the results of Karazhyra deposit development will affect considerably the development of radiological situation at the Balapan site.

The researches have shown that ^{137}Cs, ^{90}Sr concentrations in the groundwater on this site are below $IL_{нас}$ (Interference level based on annual specific activity) set forth by NRB-99. At the same time, ^{3}H concentration in the zone of Chinrau fault influence is much higher and varies from $1.4*10^5$ to $1.6*10^5$ Bq/kg [6]. For the general understanding of the situation, it should be remembered that water with more than $7.7*10^4$ Bq/kg concentration of tritium is classified as the radioactive waste [10].

Hence, the process of depression cone progress in the eastern direction constitutes a danger that the groundwater contaminated with artificial radionuclides may get to the open-pit.

2.2.3. Atmospheric pollution due to dust formation from contaminated soil

Numerous nuclear weapons tests including those at STS have broadened the area of propagation of artificial radionuclides and included them in various natural cycles: biochemical, hydrochemical, geochemical, atmospheric, and other. The redistribution of activity on the territory of polygon and in the surrounding area proceeds up to now. Having fallen in some form on the ground surface, radionuclides are redistributed and migrate due to transport by wind (dust storm, step fires, etc.) and surface and ground water.

The results of the research and model calculations show that the radioactive air pollution at STS can be dangerous only for a human being present directly on the territory of radiation-hazardous objects and only when the air contains a lot of dust. Outside the territory of the test site, the volumetric activity of artificial radionuclides is much lower than the regulatory value. Thus, for instance, in Sarzhal and Kurchatov settlements the volumetric activity of $^{239+240}Pu$ radionuclides is respectively 352 and 25,000 times lower than the permissible value, however, much higher than the radionuclide concentration in air of the cities more remote from the test site.

The long-term studies at STS [11] have shown that on large-area sources of day surface contamination with radionuclides such as the "Experimental field", significant radioactive contamination of surface air is possible only in case of technogenic dusting (road traffic and other operations causing much dust), and steppe fires.

The works on opencast mining of the deposit are such dust-raising works which result in the internal irradiation due to inhalational intake of radionuclides and require monitoring of the content of artificial radionuclides in the atmospheric air. Under these conditions, it should be taken into consideration that the territory of Karazhyra deposit is close to the sites of nuclear test sites where spots of day surface contamination had been formed. By the wind transport, radioactive products from the contaminated sites can get to the atmospheric air of the work area of deposit. Under certain circumstances such as the dust storms, this factor can contribute much to the formation of irradiation doze of personnel by inhalation.

It should also be noted that according to the recent research, for radiological monitoring in the areas of economic management in the territory of STS, besides the above radionuclides, also the concentration of tritium in the atmospheric air should be controlled. Tritium gets to the atmospheric air due to evaporation of ground and surface water. Thus in the air samples taken in different locations of STS territory up to 240 Bq/m^3 of tritium has been found. For the territory of the deposit, a possible real source of tritium from the air is the Shagan River located 15 km away from the open-pit. The tritium concentration in the river water is up to 7*10^5 Bq/kg[12].

Hence under certain weather conditions, it is not impossible that tritium together with the atmospheric air gets to the deposit borders. For more detailed and reliable assessment of possible radiation doses, tritium concentration in the air should be monitored regularly.

3. GENERAL METHODOLOGY OF WORKS

Based on the foregoing, we identified the following set of objects for our study at the territory:

- day surface sections of land allotment involved, according to the Plan of Works, in the development and operation;
- production and residential buildings at the open-pit and field camp;
- work places, plant and equipment;
- personnel;
- service roads;
- first-bench overburden rock;
- atmospheric air of work area to determine the concentration of artificial radionuclides coming from the nuclear weapon sites by secondary transport;
- underground and drainage water from hydrogeological wells and evaporation pond;
- deposit products (produced coal).

The research methods included field measurements of radiation parameters and laboratory analyses.

The measurements of radiation parameters included:

- radiation reconnaissance survey of day surface of dumps and roads in "Search" mode;
- radiometric measurements of NRD and density of surface pollution by α- and β-emission radionuclides in fixed points; and
- radiation monitoring of work places and equipment.

The field investigations included:

- sampling of soil and produced coal;
- sampling of groundwater from observation wells; and
- sampling of air aerosols.

At the end of sampling, all samples have been brought to the laboratory for testing.

The laboratory tests include the analysis of soil, water and atmospheric air samples by γ-, β-, α-spectrometry methods with preliminary chemical isolation to determine the concentration of natural and artificial radionuclides. [13].

4. RESULTS

By now, big actual material on the works executed on the deposit has been accumulated. Its scope (number of measurements and laboratory analyses) is presented in Table 5.

Table 5.

Scope of actual material on all types of field and laboratory tests

Type of measurement or sample	1998	2003	2004	2005	2006	2007	2008	2009	2010
	Results of radiometric control, number of measurements								
Radiological monitoring in fixed points of day surface	*	9	87	4	5	4	4	4	4
Radiological monitoring of designed roads	*	5	5	5	8	8	5	5	5
Radiological monitoring of first-bench overburden rock	*	*	*	*	16	10	10	11	11
Radiological monitoring of personnel locations	*	9	*	*	*	*	31	40	30
Radiological monitoring of plant and equipment	*	*	*	*	7	20	29	40	30
Radiological monitoring of coal	*	2			4	3	4	8	8
Selective monitoring radiation dose control of personnel	*	*	*	*	12	20	16	17	16
EEVA measurements of radon in production premises, at the mine and field camp	*	*	*	*	2	8	-	-	-
Number of analyses (spectrometry)									
Soil of daylight surface sections (spectrometry)	*	2	16	4	5	4	4	4	4
Road soil	*	5	5	25	8	8	5	5	5
Rock blocks with excessive concentration of NRD	*	*	6	10	16	10	10	11	11
Drainage and ground water	*	27	39	33	35	26	62	80	92
Air aerosols	*	2	8	8	12	9	*	6	8
Water vapor	*	*	*	*	11	*	4	9	12
Workers' urine	*	-	-	-	-	-	20	20	21
End products (coal)	*	2	8	4	4	3	4	8	8
The sign * means that summary data are already available; the exact number of measurements or samples is not known									

4.1. Conditions of work areas of personnel and transport mining equipment

The objects of radiological monitoring were the work places (excavator and dump truck cabs) and permanent and temporary locations of the deposit mining personnel. Table 6 includes the results of long-term radiometric measurements.

Table 6.

Results of radiometric monitoring of transportation facilities and places of temporary and permanent stay of personnel

Type of measurement	2003	2004	2005	2006	2007	2008	2009	2010
	Average value (min – max)							
Density of surface α-radiation, paricles/(min*cm²)	<0.2	<0.2	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2
Density of surface β-radiation, paricles/(min*cm²)	<10	<10	<10	<10	<10	<10	<10	<10
EDR, μSv/h	0.08 (0.06-0.11)	<0.10	0.17	0.10 (0.09-0.12)	0.12 (0.09-0.17)	0.11 (0.09-0.15)	0.12 (0.1-0.15)	0.13 (0.15-0.12)

Based on the data above, it can be mentioned that EDR values on the territory are at the background level for this area, and the density values of α-particle and β-particle fluxes in all survey points do not exceed the detection limit of the measurement instruments used. It means that the personnel and vehicles observed the limitations set for the movement routes and were not exposed to accidental radioactive contamination in potentially hazardous areas.

4.2. Soil conditions

4.2.1. First-bench overburden rock

During the works on exploration of Karazhyra deposit, based on gamma ray logging of exploratory wells in the overburden strata a layer with elevated natural radioactivity was discovered.

A zone with elevated concentration of natural radionuclides (NRD) is located in the upper part of the open-pit, and the rock depth with maximum gamma emission is within 3.6–17.0 m range. Lithologically, the radioactivity intervals are represented by oxidized coal, siltstone, argillite, clay and sandstone. According to the preliminary data, two sections with abnormal radioactivity have been delineated. The rock radioactivity is at the rate up to 280 micro-roentgen/hour (EDR). To ensure radiation safety of works, a Program on the excavation and storing of rock with elevated NRD values has been prepared and approved. The mining project envisages drilling of blocks A and B with 9.7 thousand cubic m total rock volume spreading on 12.0 thousand square m area, of 1.2 m average thickness. Figure 4 shows the layout of blocks A and B and storage areas for the rock of these blocks [14].

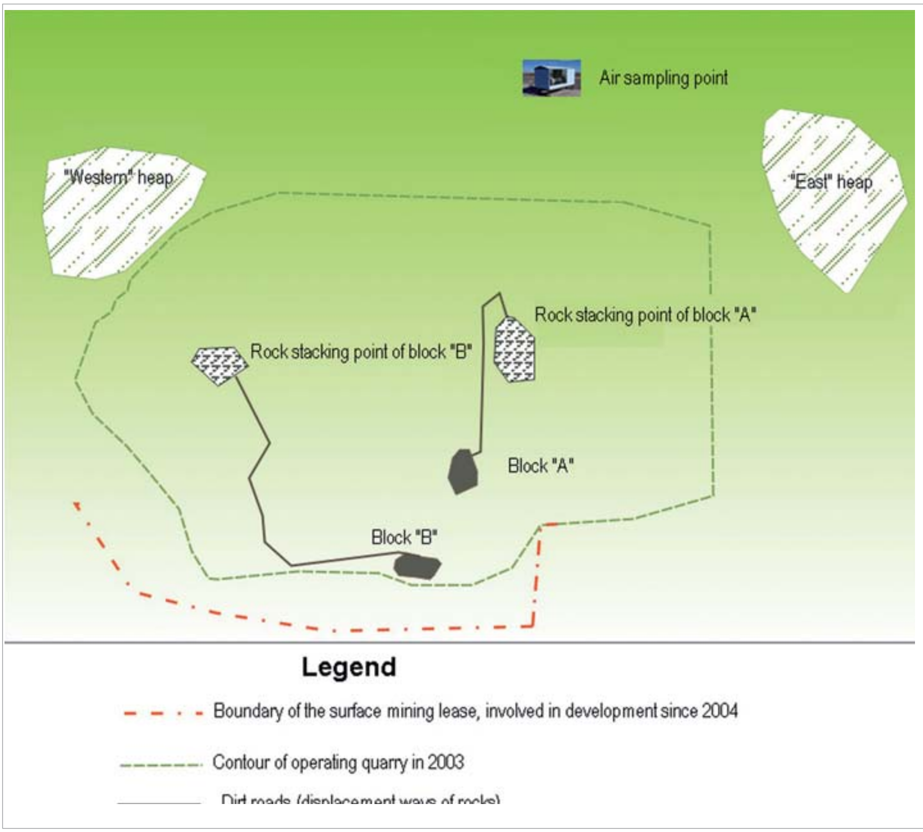


Figure 5. Layout of A and B blocks and storage areas for the rock of these blocks

Block A. Mining of Block A in the open-pit was carried out in 2002. For the sake of safety, NNC RK had developed and implemented the "Program of Radiation Monitoring of Works at Mining and Storing of Rock with Elevated Concentration of Natural Radionuclides in Block A of Karazhyra Open-Pit" (Figure 6). технологических автодорог карьера, представлены в таблице 11.

Figure 6. General view of Block A fragment before mining
(dark-color stratum is the rock with elevated NRD concentration)

The Program provides mining Block A of 4.05 thousand cubic m volume of rock spreading on 3.0 thousand square m area of 1.35 m average thickness. The anomaly in the area of Block A is stretched out in the north-western direction as a band of 14 to 50 m width and 83 m length. The NRD concentration in Block A soil is as follows: $7.7*10^3$ Bq/kg for ^{226}Ra, 220 Bq/kg for ^{232}Th and 250 Bq/kg for ^{40}K.

According to the results of gamma-spectrometry analysis of soil samples, the space distribution of NRD in the stratum both in plan and in the open-pit is not uniform. Samples of ^{226}Ra with specific activities $3*10^3$ to $5*10^3$ Bq/kg make 18% of sampled points, and those with specific activity of $5*10^3$ to $7*10^3$ Bq/kg - 5% (3 points) and are spatially located near the epicenter of Block A (Well No 130 PO) in the oxidized coal stratum.

The specific activities of ^{226}Ra samples less than 85 Bq/kg have been recorded in 32 points (60% of sampled points). The maximum values for ^{232}Th and ^{40}K are 220 Bq/kg and 250 Bq/kg, respectively. It is also found that at an increase in the specific activity of ^{226}Ra, the content of ^{232}Th decreases. The peculiarity of distribution of these radionuclides in Block A rock is shown in Figure 7.

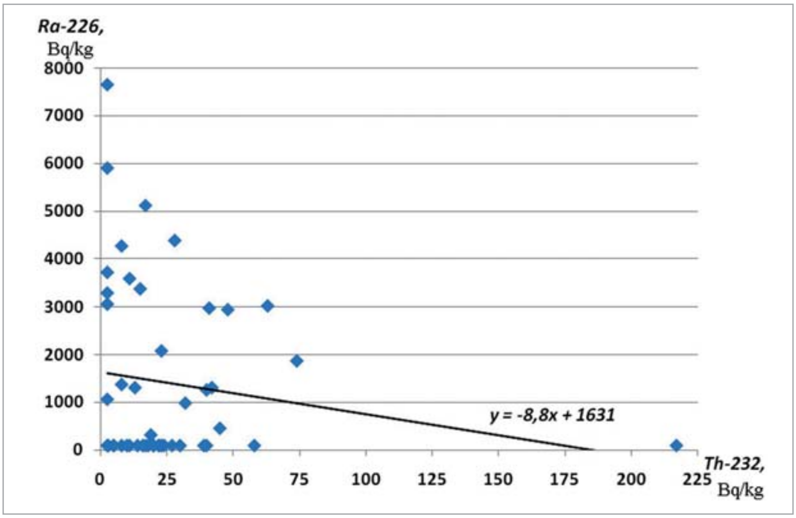


Figure 7. Block A. Concentration of ^{226}Ra and ^{232}Th in soil

In accordance with the sanitary rules in force, a controlled variable of material radioactivity is the effective specific activity (A_{eff}) determined from the assessment of contributions of individual natural radionuclides into the formation of external gamma irradiation doze:

$$A_{eff} = A_{Ra} + 1.3A_{Th} + 0.09A_K,$$

where A_{Ra} and A_{Th} is the specific activity of ^{226}Ra and ^{232}Th present in the radioactive equilibrium with the other series terms, ^{238}U and ^{232}Th respectively; and A_K is the specific activity of ^{40}K.

It follows from the obtained data that ^{226}Ra has decisive importance for the formation of A_{eff} and ^{232}Th and ^{40}K are of minor importance. During preliminary survey of Block A it was found that the lowest concentrations of ^{226}Ra are typical for the southern and north-eastern block borders where A_{eff} was 95 to 165 Bq/kg at 10 to 50 micro-roentgen/hour EDR values in sampling points, and beta-particle flux density (BPFD) from 8 to 32 particle/min*cm^2. On the whole, during the works on Block A it was found that A_{eff} concentration tends to increase from the periphery to the center of the block. Maximum values have been recorded in one point where A_{eff}=7.7*10^3 Bq/kg. The radiation parameters in the sampling point are EDR =160 micro-roentgen/hour and BPFD = 90 particle/min*cm^2. According to the survey of bench surface in search mode, the averaged thickness of layer with 30 to 60 micro-roentgen EDR is 0.45 m. The length of anomalous interlayers in 3 points is 1.5-2.0 m at 0.1-0.15 m thickness of layer with EDR from 60 to 100 micro-roentgen/hour.

Block B. The radiation safety of works at Block B was assured taking into consideration the previous experience. The area of overburden rock with elevated radioactivity of natural radionuclides on Block B is 9.0 thousand square m, rock volume is 5.67 thousand cubic m, and stratum thickness is 0.63 meters. The total volume of overburden rock to be disposed at 10 meters thickness of overburden layer is 90 thousand m^3. Laboratory analyses have shown that maximum concentrations of ^{226}Ra and ^{232}Th in Block B are much lower, 3140 and 50 Bq/kg respectively and the concentration of ^{40}K is, on the contrary, higher: up to 400 Bq/kg. At the same time, as opposed to Block A, in the rock of Block B the concentrations of ^{232}Th increase on an increase in the concentration of ^{226}Ra (Figure 8).

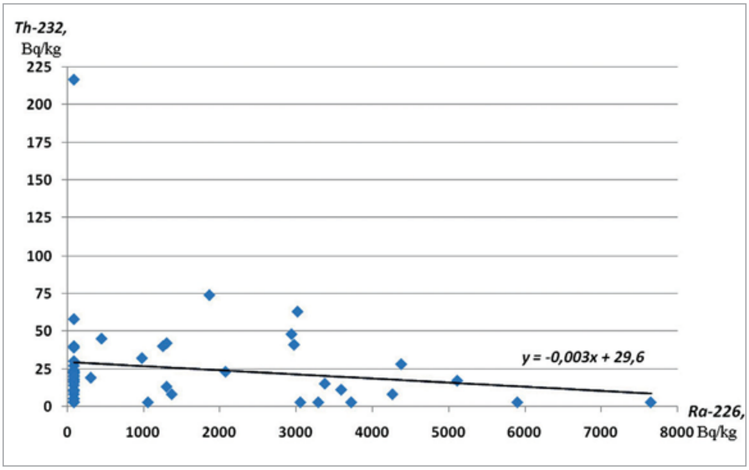


Figure 8. Block B. Concentration of ^{226}Ra and ^{232}Th in soil

To reduce the risk of personnel irradiation and restrict the environmental pollution, measures on providing radiation safety during mining and storing of rock with elevated radioactivity have been developed. The safe technology measures involve the use of specially allocated set of mining equipment (excavators, bulldozers, dump trucks, etc.) not to be used during this time for other works; for personnel: special clothes and breathing protection equipment, safety briefing on work with radioactive substances; in case of possible radioactive contamination of personnel, the storing area is provided with a site to drain water used for washing directly to the storage area.

The NRD concentration in the occupational dust on work places (excavator, BelAZ and bulldozer cabs) was monitored during each shift and showed average-monthly concentrations. Operational data on the average-shift dust concentrations were based on 5-9 point samples taken during the most typical operations and between them with the subsequent calculation of average concentration. According to the monitoring results, the dust concentration on work places during the whole work period does not exceed 0.7 mg/m^3. The maximum expected volumetric activity is 0.005 Bq/m^3 for ^{226}Ra and 0.0003 Bq/m^3 for ^{232}Th. Hence, the volumetric activity of NRD in the air on work places during the works on Block A was lower than the volumetric activity for the community (according to Appendix 2 of NRB-99, the Permissible Volumetric Activity for the community should be 0.03 Bq/m^3 for ^{226}Ra and 0.0049 Bq/m^3 for ^{232}Th).

Hence, due to a number of undertaken measures, the radiation dozes do not exceed the limits permitted for the community.

Since during the works on selective excavation of block rocks with elevated NRD concentration it was found that the spatial distribution of natural radionuclides in the overburden rock is not uniform, it is possible that the stratum of the first-stage oxidized coal can have small anomalous sections not identified by the exploration wells. This circumstance requires carrying out periodic survey of the first-bench faces to provide radiation safety of personnel.

By 2010, the first-bench plane had shifted almost for 500 m to the south from Block B. The Chart (Figure 9) shows maximum values of NRD concentration in the first-bench rock stratum found during annual surveys.

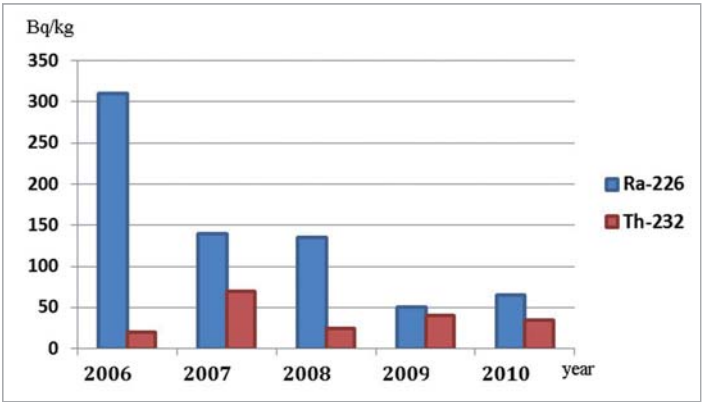


Figure 9. Maximum specific activities of NRD in rock

It can be seen from the presented data that by now the specific activity levels of NRD have reduced to the background values for this area. According to the available data, it is not expected that further shift of the first-bench plane causes a considerable increase in the NRD levels in the excavated soil. Nevertheless, to provide radiation safety of personnel, periodic survey of the first-bench faces will continue due to the existence of possible small anomalous sections in the first-bench rock not found by exploration wells. Table 7 lists the results of laboratory analyses of the first-bench rock samples.

Table 7.

Results of laboratory analyses of rock with elevated NRD concentration

Component	2003	2004	2005	2006	2007	2008	2009	2010
	Average value (Min - max), Bq/kg							
^{40}K, Bq/kg	(69-346)	146 (<14-297)	133 (<14-297)	49 (41-363)	-	134.5 (40-330)	433 (170-590)	250 (330-120)
^{226}Ra, Bq/kg	(9-2807)	260 (<1-1115)	234 (<1-1115)	134 (3-306)	57 (142-14)	(<2-135)	38 (26-48)	35 (15-65)
^{232}Th, Bq/kg	(5-39)	19 (<4-33)	14,8	12 (2-18)	34 (21-66)	(<4-25)	34 (24-42)	22 (10-35)
^{241}Am, Bq/kg	-	1.2 (<0.2-2)	(<0.2-1)	<1	<2	<2	<2	<2
^{137}Cs, Bq/kg	-	<1	<1	<4	<2	<2	(<1-17)	<2

The γ-spectrometry measurements of rock samples taken from the bench surface show the specific activity of artificial radionuclides to be lower than the minimum detectable activity of the spectrometer used. The concentration of natural radionuclides is in the range below the minimum significant content of radionuclides indoors and at work places.

4.2.2. Conditions at the day surface sections of the mine allotment involved in the development according to the plan of mining operations

In 2001, the staff of NNC RK assessed the level of radioactive contamination of the day surface of the Karazhyra coal deposit territory allotted for the development [15]. Based on the ground sampling results, a map of surface contamination has been prepared. For most of the tested samples the specific activity of $^{239+240}$Pu is within the range of up to 100 Bq/kg and only in two points elevated values with 180 Bq/kg maximum have been recorded. At the same time, within the anomalous sections, radiometric measurements with a denser network have been carried out. By detailed investigation, no foci of radioactive pollution hazardous for the personnel engaged in the deposit development have been found.

Nevertheless, it is intended to perform annual survey of the day surface sections of the mine allotment included in the Plan of mining operations to assure radiation safety of the personnel and to study the dynamics of radiological situation on the day surface of the deposit area. The survey includes field radiometric measurements and sampling for laboratory analyses to determine the concentration of artificial radionuclides. Various structures and objects that could be brought to the deposit area from nuclear explosion sites have also been surveyed.

Preliminarily, the day surface radiation monitoring was conducted in search regime. The locations with maximum EDR values have been distinguished as soil sampling locations to test for the concentration of artificial radionuclides. In the sampling locations, measurements of density of surface contamination by alpha and beta emission radionuclides have been carried out. The results of day surface radiation monitoring are listed in Table 8.

Table 8.

Results of radiometric monitoring and laboratory analysis of soil samples taken in fixed points of the day surface

Measurement type	2005	2006	2007	2008	2009	2010
	Average value (min-max)					
Surface α-radiation density, particles/(min*cm^2)	<0.2	<0.3	<0.2	<0.2	<0.2	-
Surface β-radiation density, particles/(min*cm^2)	<10	<10	<10	<10	<10	<10
EDR at surface, μSv/h	0.12 (0.11-0.14)	0.1 (0.11-0.15)	0.115 (0.11-0.12)	0.14 (0.12-0.17)	0.14	0.115 (0.09-0.14)

Based on the data above, a conclusion can be drawn that the radiation parameters of the day surface do not exceed the background values typical for this area. The radiation parameters for the whole monitoring period are found to be relatively stable, and no anomalously high values are expected.

The results of laboratory analyses of rock samples taken on the day surface area are listed in Table 9.

Table 9.

Results of laboratory analyses of day surface samples

Component	2004	2005	2006	2007	2008	2009	2010
	Average value (min-max)						
^{40}K, Bq/kg	-	474 (411-530)	526 (416-639)	-	528 (381-730)	470 (330-650)	237 (200-280)
^{226}Ra, Bq/kg	38 (34-45)	36 (32-42)	40.4 (31-79)	30.5 (9-40)	17 (13-30)	43 (40-50)	37 (30-45)
^{232}Th, Bq/kg	30 (28-35)	29 (24-38)	25.6 (22-30)	33.3 (25-43)	20 (15-25)	31 (25-35)	26 (20-30)
^{210}Pb, Bq/kg	-	-	86 (63-106)	-	-	-	-
^{241}Am, Bq/kg	4.6 (2.6-8.1)	4.5 (1-7)	4.4 (2-7)	<2	(<1-5)	<1	<2
^{137}Cs, Bq/kg	36 (27.9-49.2)	31 (17-46)	35 (18-53)	(<2-49)	(<2-35)	(<2-20)	20 (15-25)
^{90}Sr, Bq/kg	-	-	16.5 (9-24)	-	-	(<6.6-10.5)	<3 – 4
$^{239+240}$Pu, Bq/kg	31.6	-	59 (40-78)	-	-	16 (10-22)	-

The monitoring data on the day surface of mine allotment area included in the Plan of mine operations for 2010 showed that the specific activities of artificial radionuclides and field radiometric measurements on this area are not different from the areal survey data of the previous years. This means that during the period under consideration no additional radioactive contamination of the day surface within this area has occurred.

4.2.3. Service roads' conditions

Service roads are surveyed once a year to assess possible transport of artificial radionuclides from nuclear test sites to the open-pit area and their further propagation by vehicles. The radiation monitoring is performed in search regime. Soil samples are taken in the points of maximum equivalent doze rate for the comprehensive analysis of concentration of natural and artificial radionuclides. In the sampling points, the density of surface contamination with alpha and beta emitting radionuclides is measured.

The results of radiation monitoring of service roads are presented in Table 10 below.

Table 10.

Results of radiometric monitoring on motor roads

Measurement type	2003	2004	2006	2007	2008	2009	2010
	Average value (min-max)						
Surface α-radiation density, particles/(min*cm^2)	<0.3	<0.3	<0.3	<0.2	<0.2	< 0.2	-
Surface β-radiation density, particles/(min*cm^2)	<10	<10	<10	<10	<10	<10	<10
EDR at surface, μSv/h	0.11 (0.1-0.12)	0.13 (0.12-0.14)	0.11 (0.10-0.12)	0.1 (0.05-0.13)	0.11 (0.10-0.12)	0.12 (0.11-0.13)	0.104 (0.09-0.12)

The results of laboratory analyses of soil samples taken from the open-pit service roads are presented in Table 11.

Table 11.

Results of laboratory analyses of soil samples from motor roads

Component	2003	2004	2005	2006	2007	2008	2009	2010
	Average value (min-max)							
^{40}K, Bq/kg	146 (89-274)	268 (213-293)	362 (310-424)	288 (65-608)	-	202 (120-250)	280 (170-400)	224 (120-400)
^{226}Ra, Bq/kg	6.5 (<5-7)	19 (11-29)	32 (22-56)	24 (6-30)	44 (28-100)	(<3-40)	34 (20-45)	23 (30-15)
^{232}Th, Bq/kg	10.5 (<4-18)	19 (16-20)	16 (14-23)	20 (6-30)	37 (18-99)	(<6-15)	21 (15-30)	18 (15-25)
^{241}Am, Bq/kg	-	<0.3	<0.9	4 (0.2-10)	<2	<1	<1	<2
^{137}Cs, Bq/kg	1.2 (<0.7-1.4)	(<0.5-1)	<1	15 (0.5-55)	(<1-3)	<1	<2	<1
^{60}Co, Bq/kg	-	-	-	-	<3	<2	-	-
^{210}Pb, Bq/kg	23.6 (17-35)	-	-	-	-	-	-	-

The obtained results show that the radioactive contamination of motor roads does not exceed the respective values for the day surface. It means that no radionuclide contamination of road surface happened during the deposit development.

4.3. Mined coal

Coal samples from different blocks are taken every year to study the composition of natural radionuclides in the coal mined and control possible contamination with artificial radionuclides of the Karazhyra coal deposit. In addition, to determine the concentration of natural and artificial radionuclides in the ash residues of Karazhyra coal deposit, samples are regularly taken from the ash dumps of boiler plants using only Karazhyra coal deposit. The results of laboratory analyses are presented in Table 12.

Table 12.

Results of laboratory analyses of mined coal

Component	2003	2004	2005	2006	2007	2008	2009	2010
	Average value							
^{40}K, Bq/kg	290	224	<26	<28	<26	110	560	190
^{226}Ra, Bq/kg	15	30	3	4	35	<5	30	30
^{232}Th, Bq/kg	30	30	5	6	40	10	25	25
^{241}Am, Bq/kg	-	-	-	<0.5	<2	<1	<1	<2
^{137}Cs, Bq/kg	<3	<3	<3	<3	<3	<3	<3	<3
Effective specific activity, Bq/kg	78.0	84.5	11.8	14.3	88.9	27.9	113.7	80.7

The results of laboratory analyses of coal ash residues are presented in Table 13.

Table 13.

Results of analyses of coal ash samples

Sample type	Specific activity				
	^{226}Ra, Bq/kg	^{40}K, Bq/kg	^{232}Th, Bq/kg	^{137}Cs, Bq/kg	*$A_{eff,}$ Bq/kg
ash	12	273	28.1	<2	73
ash	17	307	29.5	<2	83
ash	2.3	<19.0	4.0	<2	9
ash	50±5	950±40	30±2	<2	174
ash	60±5	1000±40	30±2	<2	189
ash	30±3	280±20	30±3	<2	94
ash	45±4	310±30	45±4	<2	132

According to the sanitary rules in force, a controlled parameter of material radioactivity should be the effective specific activity (A_{eff}) determined from the assessment of contributions of individual natural radionuclides to the formation of external gamma irradiation doze. The effective specific activity is calculated using the formula provided in 5.3.4 NRB-99.

$$A_{eff} = A_{Ra} + 1{,}3A_{Th} + 0{,}09A_K,$$

where A_{Ra} and A_{Th} are the specific activities of ^{226}Ra and ^{232}Th being in equilibrium with the other members of uranium and thorium series and A_K is the specific activity of ^{40}K (Bq/kg).

It can be seen from the table that no artificial radionuclides have been found in the samples of coal or ash residues. At the same time, the effective specific activity of coal and ash comprises 114 and 189 Bq/kg respectively, which is below the regulatory level of 370 Bq/kg. Hence, the radionuclide composition of coal allows for using it as an energy feedstock, and ash residues can be used as construction materials without limitation (NRB-99 para. 5.3).

It should be noted that the concentration of natural radionuclides in the coal of the Karazhyra deposit conforms to the average-world activity of coal (Table 14).

Table 14.

Activity of the Karazhyra open-pit coal vs. average-world values

Radionuclide	World average, Bq/kg	Karazhyra open-pit, Bq/kg (average/(min – max))
^{40}K	140-850	182/(<26-560)
^{226}Ra	17-60	19/(<5-35)
^{232}Th	11-64	21/(5-40)

4.4. Conditions of air

The radioactive contamination of territory with nuclear explosion products creates a danger of not only internal irradiation. In the process of deposit development a basic way of contamination is inhalation of incoming radionuclides due to dust formation during geological prospecting, mining and construction works involving breaking of topsoil. Due to the open pit mining and ventilation of work area, the radionuclide concentration, under certain circumstances, can contribute much to the irradiation exposure of personnel from the intake. Such circumstances can arise due to natural factors (dust storms, etc.) which may result in release of radioactive products from nuclear explosion sites to the atmospheric air.

The results of laboratory testing of atmospheric air samples are presented in Table 15.

Table 15.

Results of laboratory testing of atmospheric air samples

Component	$PVA_{нас}$ (NRB-99)	2003	2004	2005	2006	2007	2008	2009	2010
		max / average							
^{40}K, Bq/m^3	31	-	-	$5.1*10^{-5}$ / $1.8*10^{-5}$	$1.1*10^{-3}$	-	-	-	$<2.4*10^{-7}$
^{226}Ra, Bq/m^3	0.03	-	-	$1.9*10^{-6}$ / $1.3*10^{-6}$	$<1.3*10^{-6}$/ $1.9*10^{-6}$	$6.44*10^{-6}$/ $1.71*10^{-5}$	-	-	-
^{232}Th, Bq/m^3	$4.9*10^{-3}$	-	-	$4.1*10^{-6}$/ $1.5*10^{-6}$	$<1.1*10^{-6}$/ $1.2*10^{-6}$	$2.24*10^{-5}$/ $9.49*10^{-6}$	-	-	-
^{210}Pb, Bq/m^3	0.11	$2*10^{-4}$ / $1.2*10^{-4}$	-	$8.1*10^{-5}$ / $4.1*10^{-5}$	$<2.2*10^{-3}$	-	-	-	-
^{241}Am, Bq/m^3	$2.9*10^{-3}$	$6*10^{-5}$ / $3*10^{-5}$	$9.3*10^{-8}$ / $4.2*10^{-8}$	$<1.5*10^{-7}$	$<10^{-7}$	$2.03*10^{-6}$/ $4.84*10^{-7}$	$<1.6*10^{-4}$/ $<3.7*10^{-6}$	$<6*10^{-7}$	$<3*10^{-6}$ / $<1.5*10^{-6}$
^{137}Cs, Bq/m^3	27	$8.7*10^{-7}$ / $6.8*10^{-7}$	$19.4*10^{-8}$ / $15.5*10^{-8}$	$<3.7*10^{-7}$	$<7.9*10^{-7}$	$3.39*10^{-6}$/ $7.09*10^{-7}$	$<2.7*10^{-4}$	$<1.3*10^{-6}$	$<9*10^{-7}$ / $<5.2*10^{-7}$
^{90}Sr, Bq/m^3	2.7	-	-	$\leq 6.3*10^{-7}$	$3.6*10^{-7}$	$<2.1*10^{-7}$	-	$0.2*10^{-4}$	-
$^{239+240}Pu$	$2.5*10^{-3}$	-	$4.9*10^{-8}$ / $3.6*10^{-8}$	$2.5*10^{-7}$	$1.03*10^{-7}$	-	-	0.0001	-

The results of laboratory testing of water vapor samples from the atmospheric air are presented in Table 16.

Table 16.

Results of laboratory testing of water vapor samples from atmospheric air

Analyzed component	PVA$_{\text{нас}}$ (Permissible Volumetric Activity) (NRB-99)	2008	2009	2010
		min/max		
^{3}H, Bq/m^{3}	1900	0.01/0.17	<0.2/10	<1

Laboratory studies of volumetric activity for natural and artificial radionuclides in air samples show that their values are at the levels a few orders below the permissible average-year volumetric activity in the inhaled air and constitute no danger.

4.5. Assessment of groundwater contamination by artificial radionuclides

4.5.1. Results of radionuclide monitoring of groundwater

The results of radionuclide monitoring of groundwater within the mine allotment have been carried out by NNC RK since 2003 [13]. The monitoring system of radionuclide migration with the groundwater is based on quarterly collection of water samples from observation wells.

To assess the character of artificial radionuclide migration processes, water samples were taken from 42 observation wells drilled within the deposit area, evaporation pond and the open-pit (Figure 10).

The water samples were analyzed for contents of ^{3}H, ^{137}Cs, ^{90}Sr, ^{239,240}Pu. The results of the laboratory analysis of groundwater samples are listed in Table 17.

Table 17.

Karazhyra area. Radionuclide concentrations in groundwater

Well No.	Sampling date	^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
463	2003-2010	<7-16	0.015	0.29	-
	2011	<13	-	-	-
467	2005-2008	<7-54	-	-	-
	2010	<7			-
468	2003-2010	<7-54	0.02	1.1	-
	2011	<13	-	-	-
	2003-2010	<7-54	0.03	0.13	-
470	2011	<14	-	-	-
472	2003-2010	<7-20	0.45	0.1	-
	2011	<13	-	<0.01	-
473	2003-2010	<7-20	0.04	0.36	-
	2011	<13	-	-	-

Well No.	Sampling date	^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}$Pu, Bq/kg
475	2003	<7	-	-	-
	2005	41	-	-	-
	2007	10	<0.005	0.01	-
476	2003	<8	-	-	-
	2007	14	<0.005	0.01	-
478	2010	<7	-	-	-
481	2003-2010	<7-54	0.01	0.74	-
	2011	<13	-	<0.01	-
482	2003-2007	<7-20	0.01	0.28	-
	2008	25	-	-	-
493	2003-2007	<7-30	0.01	0.008	<0.096
	2011	<12	-	-	-
500	2003-2008	<7-25	0.005	0.02	-
	2009	<8	-	-	-
501	2003-2010	<7-25	0.01	0.34	-
	2011	<13	-	-	-
507	2003-2007	<8 -78	<0.005	0.02	-
509	2003-2008	<7-25	0.01	0.23	-
	2009	<8	-	-	-
510	2003	11	-	-	-
515	2003-2008	<7-20	0.01	0.25	-
	2010	<11	-	-	-
518	2003-2009	<7-25	0.02	0.69	-
	2010	<8	-	-	-
520	2003-2009	<7-25	0.01	0.06	-
	2010	<8	-	-	-
529	2003-2010	<7-25	0.02	<0.1	-
	2011	<13	-	-	-
535	2003	<8	-	-	-
536	2003	<8	-	-	-
537	2003-2010	<7-22	0.01	0.4	-
	2011	<13	-	-	-
538	2003	580	0.03	<0.03	<0.099
	2004	570	0.05	0.079	-
	2005	760	0.023	0.043	<0.08
	2006	470	0.05	0.079	-
	2007	380	0.02	0.08	-
	2008	500	0.05	1.3	-
	2009	300	<0.01	0.03	0.002
	2010	250	<0.02	<0.01	-
	2011	250	-	<0.01	-

Well No.	Sampling date	^{3}H, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}Pu$, Bq/kg
539	2003	46	-	-	-
	2004	<37	-	-	-
	2005	98	0.19	0.41	-
	2007	44	0.02	0.58	-
	2008	200	0.06	0.02	-
	2009	40	<0.02	1.15	-
	2010	30	<0.1	<0.01	<0.001
540	2003	<10	-	-	-
541	2003-2010	<7-20	0.01	0.4	-
	2011	<14	-	-	-
542	2007	21	-	-	-
	2003-2010	<7-33	0.02	0.11	-
543	2011	<14	-	<0.01	-
544	2004	<40	-	-	-
545	2003-2010	<7-20	0.01	0.03	-
	2011	<13	-	-	-
546	2004-2010	<7-3	0.01	0.01	-
	2011	<16	-	<0.01	-
547	2003-2010	<7-14	0.02	<0.1	-
	2011	<13	-	-	-
548	2005	<9	-	-	-
	2007	10	<0.006	0.02	-
549	2006	<9	-	-	-
	2007	15	0.01	<0.1	-
	2008	10	-	-	-
550	2007	0,017	0.01	0.2	-
551	2007-2010	<7-23	0.01	0.2	-
	2011	<13	-	-	-
552	2008-2010	<7-20	-	-	-
553	2009	<7	<0.04	0.14	<0.001
	2010	<9	<0.01	<0.01	-
554	2010	<8	<0.1	<0.01	-
555	2010	<8	<0.01	<0.01	-
	2011	<14		<0.01	<0.002
Open pit	2004-2009	<7-23	0.3	0.84	-
	2010	<9	<0.02	<0.01	0.016
	2011	<13	-	<0.01	-
Evaporation pond	2003-2009	<7-23	0.01	1.00	-
	2010	<15	-	-	-
MSSA, Bq/kg	-	1,000,000,000	10,000	100,000	1,000
- No measurements were made.					

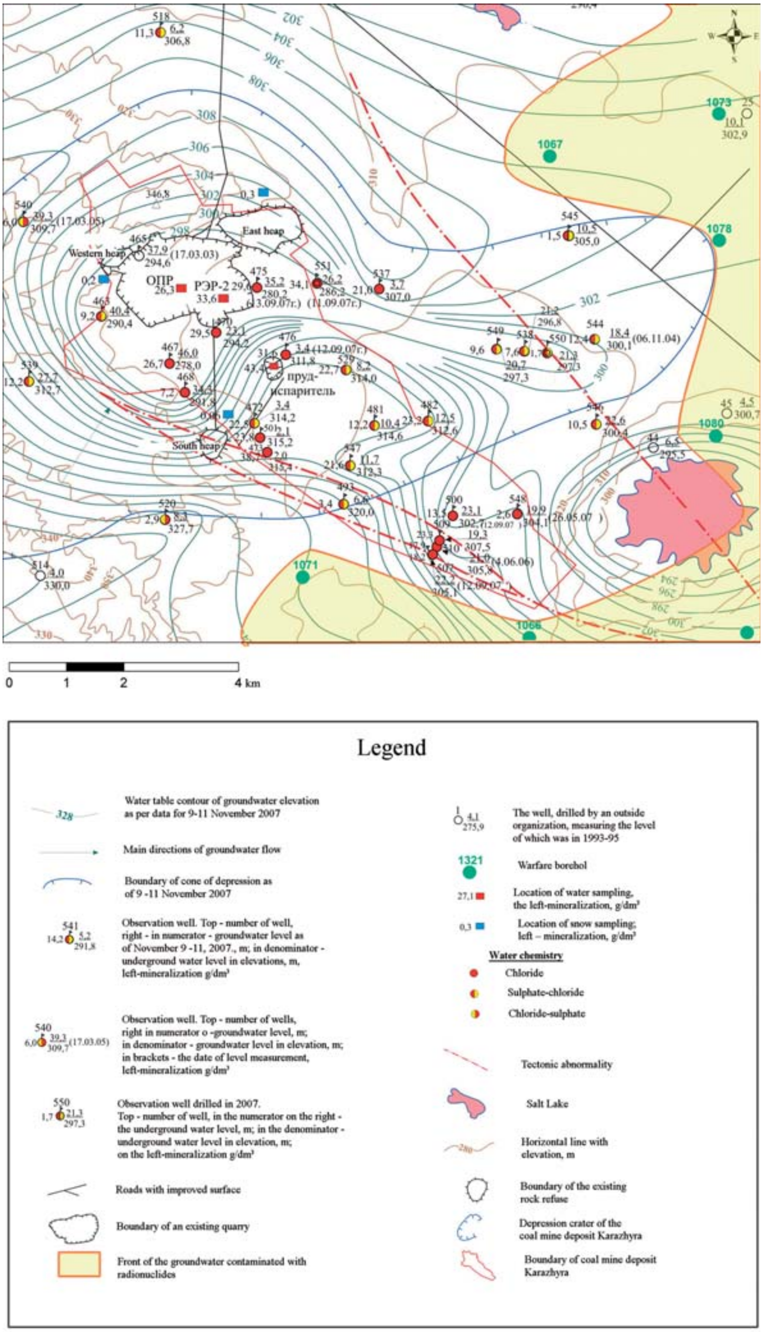


Figure 10. Karazhyra deposit. Location of wells for groundwater sampling

Analyzing the data above, it can be noted that the quantitative data on radionuclide concentration in groundwater are basically below EDR and when radionuclides are found, their concentration is generally low. Moreover, the values vary within the following ranges: ^{137}Cs from EDR to 0.3 Bq/kg; ^{90}Sr from EDR to 1.3 Bq/kg; tritium – from EDR to 760 Bq/kg; $^{239+240}$Pu from EDR to 0.016 Bq/kg. The obtained radiation hazard values do not constitute danger and do not exceed the $IL_{нас}$ (IL, Intervention levels) values set forth by NRB-99 for potable water.

An exception are the two sections of location of 538 and 539 hydrological wells where elevated tritium concentrations of up to 760 and 200 Bq/kg respectively have been recorded. These wells, compared to others, have also shown increased concentrations of ^{137}Cs and ^{90}Sr. Based on the existing hydrogeological conditions, the ingress of artificial radionuclides with underground water to these wells proceeds together with the fissure-vein water in two ways. To well 538, the contaminant flow moves along the Chinrau fault zone from the 1080 "warfare" borehole. The well 538 is located within the local discharge area. The formation of this area is, most probably, due to the aftermaths of underground nuclear explosion in the well 1080 located within the zone of f regional fault influence. The increased tritium concentrations in the well 539 are presumably due to the flow of contaminant water along the zone of Karazhira fault influence from the "warfare" borehole 1071.

It should be noted that the nature of migration processes on this section make the mining operations affect the underground hydrosphere. The point is that dewatering of the operating open pit is carried out by pumping the pit water to the evaporation pond located 1 km away. The location of the evaporation pond and contours of the cone of depression are shown in Figure 2б. During the years of the deposit development, due to the open-cut drainage, a cone of depression (cone of dewatering) has been formed on the adjoining territory. The cone of depression expands in the eastern direction at approximately 1 km per year.

In summer, part of drain water is evaporated and some volume is drained to the aquifer and returns to the pit. As a result, around the evaporation pond there forms a cone of propagating water that creates pressure head on the way of groundwater and decreases the rate of movement of cone of depression to the area of "warfare" boreholes. Hence the operation of drain water evaporation pond is one of the factors preventing the radioactive products from getting to the deposit borders together with groundwater.

The following conclusions can be made based on the survey of groundwater within the Karazhyra deposit area:

- a basic aquifer within the Karazhyra deposit is the Lower Jurassic aquifer. This aquifer accounts for the major volume of water inflow to the coal pit. The general groundwater movement is directed from south-west and west to north and north-west to the River Irtysh valley;
- on the whole, the Jurassic sediments aquifer on the deposit area includes water with the mineralization rate of 9.4-55.5 g/dm^3. By chemical composition, the water is chloride, sulfate-chloride and magnesium-sodium;
- concentrations of artificial radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}$Pu in the groundwater are much lower than the minimum significant specific activity (MSSA) and do not exceed the values for potable water set forth by NRB- 99 $IL_{нас}$.

4.5.4. Forecast evaluation of possible groundwater contamination

The hydrogeological conditions of the area and the Karazhyra deposit in terms of its open-cut mining appear quite simple. Absence of large water-bearing formations with big natural reserves and groundwater resources allows one to consider this deposit as a medium-flooded one and its operation will not evidently cause great difficulties. However, during the commercial exploitation of the deposit, serious environmental problems may arise due to the proximity to the underground nuclear test site Balapan.

At present, no widespread contamination of groundwater with radionuclides is observed. It does not mean that the situation in this area is favorable for any economic activity. The migration processes of any material with water, formation and transport of groundwater depend on many factors and take considerable time. Very low water-conveyance properties of the enclosing rock, alternation of water bearing zones of fault fracturing and Paleozoic rock bases, considerable depths of explosion epicenters and scant infiltration recharge conditions are responsible for the extremely low water exchange in the area of the Karazhyra deposit. Hence, under natural conditions, the result of underground contamination on the sections adjoining the explosion sites may some way come out in tens and hundreds of years. It is true for the natural conditions. But he situation differs when it the geological environment undergoes severe technogenic exposure, for instance, in case of commercial exploitation of the Karazhyra coal deposit. It will be noted that in the international practice there have been no cases of mineral deposit development close to sources of radioactive contamination of underground hydrosphere, in our case – "warfare" boreholes.

Formation of the dewatering cone causes an increase in the piezometric surface slopes of interstitial water what results in an equivalent increase in the processes of groundwater migration and proliferation towards the open-pit. The development of the open-cut of 200 m depth will cause an increase in the depression cone the sphere of influence of which can include the area of "warfare" boreholes.

Possible development of radioecological situation due to the growth of depression cone and flow of contaminated water to the deposit borders can be presented on a step-by-step basis in a chronological order.

At present, when uncovering the coal strata at the Karazhyra deposit, the inflow is formed by the coming natural groundwater. Simultaneously, gradual growth of general depression cone occurs. It is not impossible that subsequently this process would involve the groundwater of Chinrau and Karazhyra faults and their transformation, as the area is covered by the depression cone, to linear subsurface drains. It will intensify the groundwater proliferation towards the open-pit. With further growth of the depression cone, the role of Chinrau and Karazhyra faults will be even more important; they will cause intensification of ground water proliferation disturbing completely the natural groundwater regime in Paleozoic rocks. These are the aquifer zones of exogenic fracturing, zones of secondary fault fracturing and, in general, fissures and rock-fracture zones of any origin including seismologic fractures due to the nuclear explosions at the Balapan site.

So, we described the general nature of changes in the subsurface hydrosphere. So far, it is not possible now to predict, at which stage of the deposit mining the concentration of artificial radionuclides in the open-cut water exceeds the permissible level and whether it occurs. A detailed study of hydrogeological regime in the area of Balapan site and, particularly, the Karazhyra deposit is required. In such cases, the operational control and quality forecasts would be possible based only on the data of groundwater monitoring during which it is necessary to take into consideration some probable hydrodynamic peculiarities of inflow formation to the open cut.

4.6. Underground rock gasification at Balapan site

In addition to the hazard from artificial radiation impact at the territory of former STS, there is a number of other hazards due to the residual effects of long-term geothermal activity in the UEE epicenter zones. The Balapan site should first of all be mentioned. The basic factors causing rock gasification at this site is that a great number of UEE in boreholes have been conducted in the rock containing carbonaceous material. Presence of groundwater and high temperatures in the rock blocks enclosing central UEE zones promotes the processes of oxygen-free destruction of rock. One of the basic consequences of UEE conducted in coal-bearing rock is the gas release and formation of uncaved bags the volume of which due to gasification with time increases. More detailed description of the underground rock gasification processes at the Balapan site is given in [2].

At present, the situation at all "warfare" boreholes is monitored by NNC RK. All critical wells are subject to gas and temperature monitoring. Special observation wells have been drilled to conduct monitoring. One monitoring station has been provided to carry out round-the-clock temperature measurements at "warfare" hole 1010.

It is worthwhile noting that no disastrous events due to rock fires on the day surface currently happen. The release of gases to the day surface happens within the local sections in the area of "warfare" boreholes within 100 m from the wells. All economic entities in the area of Balapan site have been provided by NNC RK with safe route maps developed taking into consideration both the radiation factors and the hazards due to the underground rock gasification.

5. DISCUSSION OF RESULTS

Analysis of radioecological situation development in the Karazhyra deposit area based on the long-term monitoring and considering the results of earlier studies, provides the following. On the whole, the situation at the deposit is stable and does not require special radiation safety measures to be implemented. However, considering that Karahyra deposit is located at the Balapan test site of former STS, mining works on the deposit should be executed under permanent radiation control with due account of the recommendations given below.

Day surface soil. Based on the research performed, it has been ascertained that concentrations of artificial radionuclides on the day surface of the deposit territory are conditioned by mainly global fallouts, radioactive fallouts caused by the nuclear tests conducted at the "Experimental field", and contingency situations during UNE at the Balapan site. The concentration of natural radionuclides in the topsoil is typical for the soil of this area. Presence of artificial radionuclides has been revealed; their concentration is comparable with the global fallouts background. However, the potential sources of secondary radioactive contamination can be the local sites of radioactive contamination in the epicenter zones of "warfare" boreholes at the Balapan site. Consequently, the monitoring of service roads at the deposit should be maintained at the same level.

The results of long-term monitoring show that the level of radioactive contamination on day surface areas to be developed according to the Plan of Mining Operations remains constant and does not constitute any radiological hazard. It means that this type of monitoring can be considerably reduced or totally excluded from the scope of radiological monitoring.

Atmospheric air. According to the results of long-term monitoring, no presence of artificial radionuclides in the air has been found. Tritium concentration in the air of the facility does not exceed the permissible values set for by the Radiation Safety Standards regulatory doc (NRB-99) and is typical for the Balapan site. It is, however, possible that under certain circumstances the contribution of tritium to the doze can be significant due to possible emergence of tritium-contaminated water vapor from the River Shagan. Under such conditions, the tritium concentration should be regularly monitored not only on the territory of the open-piit developed but also in the locations of increased tritium concentrations in the River Shagan water. However, the number of atmospheric air samples to be tested for the concentration of ^{137}Cs, ^{90}Sr and ^{239,240}Pu radionuclides can be reduced to one sample per month.

Ground water. The basic radionuclide contaminant of groundwater spread in the area of Karazhyra deposit is the artificial tritium. The found levels of this radionuclide do not constitute radiation hazard and are much lower than the permissible values for potable water. Nevertheless, the fact of finding UNE radioactive products in the ground water dictates a necessity of more thorough investigation of their proliferation pathways and concentration dynamics in the groundwater on the deposit-adjoining territory. According to the study, a basic proliferation pass for contaminated groundwater is the junction zone of Chinrau and Karazhyra faults. It is necessary to carry out detailed study on this section and, based on the findings, adjust the volumes and parameters of groundwater monitoring. The necessity of groundwater monitoring in the area of the Karazhyra deposit raises no doubts, and considering the unique geoecological situation and prospects for the further development of STS territory, the implementation of monitoring would have a great general scientific and practical importance and, first of all, from a perspective of working out of measures and procedures to prevent the negative impact of nuclear tests on the environment. The implementation of groundwater monitoring is a complex task. Moreover, detailed studies requiring high material costs are needed. Such task cannot be adequately fulfilled by efforts of only coal-mining enterprise because on such facilities practical interests intersect with the problems of nationwide character. Only in the period from 2003 to 2006, NNC RK divisions restored and included in the regime network about 100 hydrogeological wells and drilled some additional wells at the Balapan site. Moreover, for the implementation of monitoring, as regards the facilities use, it is extremely important to provide systematic and consistent development of the network of hydrogeological regime with consideration for the nature of radioactive contamination of ground water at the Balapan site.

In such cases, operational supervision and quality prediction is possible based on only the data of groundwater monitoring the implementation of which requires considering a number of probable hydrodynamic peculiarities of the formation of inflow to the open-cut.

Radiation monitoring of work places. In the process of radiation monitoring no radioactive contamination of working surface of equipment, vehicles and personnel spaces has been recorded. The radiation parameters in all measurement points remain virtually unchanged. Nevertheless, considering the social concern of the community about the closeness of UNE, such monitoring should be continued but much reduced.

Underground rock gasification at the Balapan site. The assessment of risks for the involved rock gasification processes due to possible fires, caving of UNE well and transport of radioactive substances is still an open issue. It will be noted that now the situation with the gas content on "warfare" boreholes mouth sites is under control. Any disastrous phenomena on the test sites have not been observed, and special safety measures are not required. Nevertheless, it should be noted that all wells in which UNE had been conducted are potentially gas-bearing. In this relation, managers of companies operating on the territory of STS should prevent possible getting of people and technology to the Balapan and Sary-Uzen sections where UNE were conducted.

Karazhyra coal deposit. The research have shown that, according to the radionuclide composition, the coal can now be used as a construction material without limitation (NRB-99 Para. 5.3). Moreover, the concentration of natural radionuclides in the coal mined at the Karazhyra deposit conforms to the average-world radioactivity of coal. However, considering the specific character of works at STS, it would be useful to increase considerably the number of coal samples to determine the concentration of natural and artificial radionuclides.

CONCLUSION

The data of radioecological monitoring performed in the area of the Karazhyra deposit make it possible to state that according to all radiation control parameters the situation in the area at the moment appears favorable. The doses gained by the personnel from external gamma radiation do not exceed the permissible level regulated by NRB-99.

However, it should be taken into consideration that the developed deposit is located close to the underground nuclear sites, and the migration of artificial radionuclides in the ground water of the deposit can further increase during the deposit development. In this relation, the following package of priority measures should be taken to assure safe operations at the deposit:

- First, a detailed study of situation in the zone and on the junction of Karazhyra and Chinrau faults should be carried out. It is highly probable that the contaminated water will flow to the deposit borders exactly by these directions;
- Second, integrated exploration should be carried out to study the underground rock gasification processes in the area of nearest "warfare" boreholes so as to assess the involved risks due to possible fires and caving of UNE wells and carry-over of conserved radioactive materials.

Summing up, despite the fact that the Karazhyra deposit is located on the territory of STS, close to UNE sites, further development of the deposit is possible subject to the compliance with the requirements and recommendations of NNC RK and government agencies in charge of the public health protection and protection of the environment. Without doubt, at such level of control any undesirable tendencies in the development of the radioecological situation will not remain unnoticed, and relevant and timely measures will be taken.

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REFERENCES

1. Семипалатинский испытательный полигон. Создание, деятельность, конверсия /кол. авторов под рук. В.С. Школьника. – А: Казахстан, 2003.
   Semipalatinsk Test Site. Establishing, activities, conversion / a group authors leaded by Shkolnick V.S. – A: Kazakhstan, 2003. [in Russian]
2. Актуальные вопросы радиоэкологии Казахстана [Сборник трудов Института радиационной безопасности и экологии за 2007 – 2009 гг.] / под рук. Лукашенко С.Н. – Вып. 2. – Павлодар: Дом печати, 2010. – 527с.: ил.- Библиогр.: С.518. - ISBN 978-601-7112-32-5.
   Topical Issues in Radioecology of Kazakhstan. Issue 2 // Proc. of IRSE for 2007-2009, ed by Lukashenko S.N. – Pavlodar: Printing house, 2010. 527 pp [in Russian]
3. Отчет АО "Сары-Арка-геология" по предварительной и детальной разведке угольного месторождения "Каражыра" (Юбилейное) с подсчетом запасов угля по состоянию на 01.07.1995 г. за 1991-95гг.: отчет о НИР /рук. Коваль А.И.; исполн. Выползов В.Л., Шаймерденов Н.Р. – Семей, 1995.
   JSC "Sary-Arka-geology" report on preliminary and detailed exploration of the coal deposit Karazhara (Yubileinoye) and accounting of reserves as of 01.07.1195 // R&D report for 1991 – 1995 by Koval A.I., performed by Vypolzov V.L., Shaimerdenov N.R. – Semey, 1995. [in Russian]
4. Старков В.Д. Радиационная экология / В.Д.Старков, В.И.Мигунов. – Тюмень: ФГУ ИПП, 2003. – 304 с.
   Starkov V.D. Radiation Ecology // Starkov V.D., Migunov V.I. – Tumen, FSE IAP, 2003, 304 pp. [in Russian]
5. Ядерные испытания СССР. Семипалатинский полигон / под ред. В.А.Логачева. – Москва: ИздАТ, 1997.
   Nuclear tests in the USSR. Semipalatinsk test site / ed. by Logachev V.A. – Moscow: IzdAT, 1997. [in Russian]
6. Обеспечение безопасности бывшего Семипалатинского испытательного полигона Республиканская бюджетная программа 011 "Обеспечение радиационной безопасности" : отчет о НИР /ИРБЭ НЯЦ РК; рук. Лукашенко С.Н. – Курчатов: ИРБЭ НЯЦ РК, 2007. - 66 с.

Safety assurance at former Semipalatinsk test site. The Republic of Kazakhstan Budget Program 011 "Radiation Safety Assurance"// Report for R&D IRSE NNC RK leaded by Lukashenko S.N. – Kurchatov, IRSE NNC RK, 2007. – 66 pp. [in Russian]

7. Организация системы мониторинга состояния подземных вод на территории бывшего Семипалатинского испытательного полигона: годовые отчеты по проекту МНТЦ К-893 /исполн. Субботин С.Б., Пестов Е.Ю. – Курчатов, 2005.
   Establishing a system of monitoring for groundwaters at the former Semipalatinsk test site: annual reports under the ISTC project K-893 / by Subbotin S.B., Pestov Ye. Yu. – Kurchatov, 2005.
8. Нормы радиационной безопасности (НРБ-99): СП 2.6.1. 758-99; ввод. в действие 01.01.2000. – Алматы: Агентство по делам Здравоохранения РК, 1999. - 80с. – ISBN 9965-501-42-4.
   Radiation Safety Standards (NRB-99) regulatory document. Almaty 2000, 80 pp. [in Russian]
9. Семипалатинский испытательный полигон. Современное состояние: научно-популярное издание. – Павлодар: Дом печати, 2008. – 40 с.
   Semipalatinsk test site. Present state: popular science issue. – Pavlodar: Dom Pechati printing house, 2008, 40 pp. [in Russian]
10. Годовые отчеты о проведении радиоэкологического мониторинга и радиационного контроля на угольном разрезе "Каражыра": отчет о НИР (годовой отчет) /рук. Лукашенко С.Н.; исполн. Субботин С.Н. - Курчатов: ИЯФ НЯЦ РК, 2002-2007.
    Annual reports on radioecological monitoring and radiological control at the coal pit Karazhyra: R&D annual reports by Lukashenko S.N., Subbotin S.N. – Kurchatov: INP NNC RK, 2002 – 2007. [in Russian]
11. Годовые отчеты о проведении радиоэкологического мониторинга и радиационного контроля на угольном разрезе "Каражыра": отчет о НИР (годовой отчет) /рук. Лукашенко С.Н.; исполн. Субботин С.Н. - Курчатов: ИРБЭ НЯЦ РК, 2007-2010.
    Annual reports on radioecological monitoring and radiological control at the coal pit Karazhyra: R&D annual reports by Lukashenko S.N., Subbotin S.N. – Kurchatov: IRSE NNC RK, 2007 – 2010. [in Russian]
12. Отчет по программе "Радиационный контроль по отработке и складированию пород с повышенным содержанием естественных радионуклидов блока А разреза "Каражыра": отчет о НИР / рук. Лукашенко С.Н.; исполн. Субботин С.Б. - Алматы: ИЯФ РГП НЯЦ РК, 2002.
    Report under the Program "Radiological control over development and storage of rocks with high contents of natural radionuclides at the Block A at the Karazhyra open pit: R&D report by Lukashenko S.N., Subbotin S.N. – Almaty: INP NNC RK, 2002. [in Russian]
13. Отчет по оценке уровня радиоактивного загрязнения трансурановыми элементами дневной поверхности территории земельного отвода отработки

угольного месторождения "Каражыра" : отчет о НИР / рук. Лукашенко С.Н.; исполн. Субботин С.Б. – Алматы: ИЯФ РГП НЯЦ РК, 2001.
Report on the assessment of radiological contamination with transuranium elements of the day surface at the land allotment of the coal deposit Karazhyra: R&D report by Lukashenko S.N., Subbotin S.N. – Almaty: INP NNC RK, 2001. [in Russian]

14. Субботин С.Б. Вопросы миграции техногенных радионуклидов с подземными водами в районе площадки Балапан бывшего СИП / С.Б. Субботин // Ядерная и радиационная физика: доклад на V междунар.конф. 26-29 сентября, 2005. – Алматы: ИЯФ, 2005. – С.71-83.
Subbotin S.B. *The Issues of Migration of artificial radionuclides with ground waters in vicinity of Balapan Site of the former STS* //– paper presented and Proc. of the 5th International Conference Nuclear and Radiation Physics 26 – 29 Sept., 2005. Almaty: INP NNC RK, 2005, pp.71-83.

ҚАРАЖЫРА" КӨМІР КЕНОРНЫНЫҢ АУМАҒЫНДАҒЫ РАДИОЭКОЛОГИЯЛЫҚ ХАЛ-АХУАЛ

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Бұл жұмыста, бұрынғы Семей сынақ полигонының (ССП) "Балапан" алаңында орналасқан "Қаражыра" көмір кенорнының аумағында көптеген жылдар бойында өткізілген радиоэкологиялық зерттеулердің деректері келтірілген. Кенорнының аумағындағы жер бетіндегі техногенді радионуклидтердің құрамы, негізінен ғаламдық түсулермен шартталғаны анықталды. Кенорнындағы өнімнің ауадағы, топырақтағы радионуклидтерінің құрамының радиациялық параметрлерінің мәні еш қатер тудырмайды. Жабдықтардың, көлік құралдарының, қызметкерлердің тұрғын-жайларда болған кезінде радиоактивті ластануы тіркелген жоқ.

Кенорны орналасқан аумақтың радиоэкологиялық хал-ахуалын дамытуды болжау үшін қажетті деректерді алу үшін және кенорнын меңгерудің қауіпсіздігін қамтамасыз ету мақсатында радиоэкологиялық мониторинг пен радиациялық бақылауды одан әрі жүргізу үшін ұсыныстар берілді.

Түйін сөздер: кенорны, "Балапан" алаңы, гидрогеология, радионуклидті ластану, мониторинг, жерасты ядролық жарылыстары.

РАДИОЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ ТЕРРИТОРИИ УГОЛЬНОГО МЕСТОРОЖДЕНИЯ "КАРАЖЫРА"

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В настоящей работе представлены данные многолетних радиоэкологических исследований на территории угольного месторождения "Каражыра", расположенного на площадке "Балапан" бывшего Семипалатинского испытательного полигона (СИП). Установлено, что содержание техногенных радионуклидов на дневной поверхности территории месторождения обусловлено, в основном, глобальными выпадениями. Значения радиационных параметров, содержания радионуклидов в грунтах, воздухе, продукции месторождения не представляют опасности. Радиоактивного загрязнения оборудования, транспортных средств, помещений пребывания персонала не зафиксировано.

Даны рекомендации по дальнейшему ведению радиационного контроля и радиоэкологического мониторинга с целью обеспечения безопасности освоения месторождения и получения необходимых данных для прогноза развития радиоэкологической обстановки на территории расположения месторождения.

Ключевые слова: месторождение, площадка "Балапан", гидрогеология, радионуклидное загрязнение, мониторинг, подземные ядерные взрывы.

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RADIOLOGICAL SITUATION IN THE TERRITORY OF "BAITEMIR" MINEFIELD

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The paper presents the results of comprehensive radiological study at "Baitemir" minefield located in the territory of the Semipalatinsk Test Site within two regions - Pavlodar and East-Kazakhstan oblasts. Total area of the field is 40 km^2. In the course of the work we carried out an assessment of the current radiological state of the environment: soil, air basin, vegetation, wildlife. Content of artificial radionuclides in the environment within the field is due to radioactive fallouts caused by the first thermonuclear test and two hydronuclear tests. The analysis of areal distribution of artificial radionuclides identified areas with elevated values of their specific activities. Based on the level and nature of contamination we distinguished three Zones, for each of which we determined average specific activity of radionuclides in the soil cover. Territories of Zone I and Zone II are more contaminated with artificial radionuclides, and Zone III can be considered conventionally clean area. Maximal specific activities of radionuclides ^{137}Cs and ^{90}Sr are below the levels that characterize the ecological status of the territories as "relatively satisfactory situation". The content of radionuclides in vegetation, water and air, as well as expected content in foods of animal and plant origin is much lower than permissible levels. Dose loads to the population for each Zone was estimated considering content of radionuclides in the environment and food. Subject to the "worst" scenario, a "subsistence farmer", the expected annual effective dose per person will be 0.93 mSv, which does not exceed the dose limit of 1 mSv per year as established by *Radiation Safety Standards* in Kazakhstan. However, if the expected dose exceeds 0.3 mSv/year within the territory, it is needed to take protective measures to limit public exposure. Despite the fact that, given the existing regulatory requirements of RK the entire explored territory can be used without restrictions, it is not recommended to transfer this territory for agricultural use. Based on the radiation exposure assessed for personnel in the event of economic activity within the investigated area it is proposed to transfer "Baitemir" field lands for industrial, transportation, communications, defense and other non-agricultural purposes.

Keywords: "Baitemir" field, nuclear tests, radioecology, radioactive contamination, radionuclides, soil, vegetation, food, behaviour scenarios, annual effective dose

INTRODUCTION

In the former Semipalatinsk Test Site (STS) currently various economic activities, including mining are in progress. Therefore, there are issues of radiation safety of staff engaged in the works at the Test Site. The current status of STS is defined by the Government of the Republic of Kazakhstan dated February 7, 1996 No 172 "On the transfer of lands of the former Semipalatinsk Nuclear Test Site in the reserve lands". The STS territory belongs to the lands where nuclear tests were carried out, and any activity at the site, in accordance with the Law "On the Use of Atomic Energy", can be performed only after appropriate licenses are obtained. Carrying out works without a license is only possible if the status of STS lands will be altered. Reserve lands are granted to the property or land tenure for agriculture, industry and other purposes in the order of and on terms established by the Land Code of the Republic of Kazakhstan "Code of the Republic of Kazakhstan" dated June 20, 2003 No 442. According to Article 143 of the Land Code: "The plots of land, where nuclear weapons were tested, may be granted by the Government of the Republic of Kazakhstan for property or land tenure only after completion of all measures on elimination of consequences of nuclear testing and a comprehensive ecological survey if there is a positive confirmation of the Ecological Expertise".

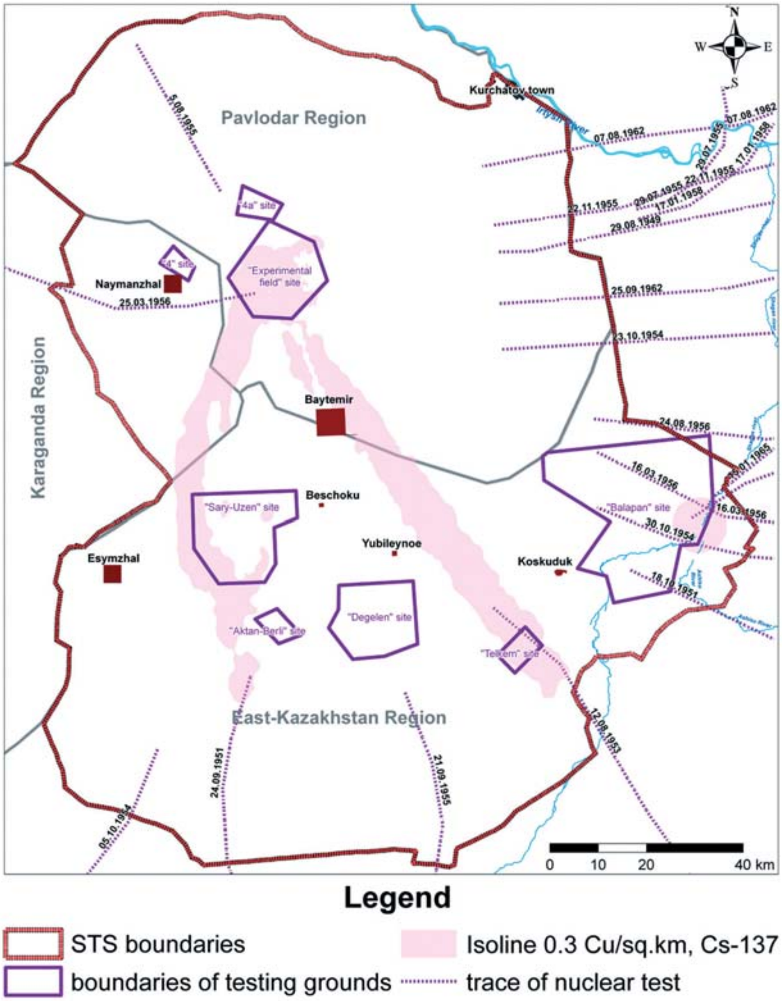


Figure 1. Map of deposits at the test site

In order to examine the possibility of releasing STS lands, where "Baitemir" field is located, to civilian use, the Institute of Radiation Safety and Ecology conducted comprehensive environmental studies that are required by the Land Code. The map (Figure 1) presents positions of nuclear testing sites, traces and trace axes of the major dose-forming atmospheric nuclear testing and location of the main fields where "FML Kazakhstan" Ltd. is operating in the Test Site territory. The main activity of the enterprise is exploration and subsequent extraction of precious metals (gold, silver, platinum) and base metals (copper, lead, zinc, nickel, cobalt, aluminum, magnesium, tungsten, molybdenum, tin). "FML Kazakhstan" Ltd. operates in areas: north-west (commercial discovery "Naimanzhal"), central (commercial discovery "Baitemir", "Beschoku", "Yubileynoye") and southeast (commercial discovery "Koskuduk").

1. SOURCES OF RADIOACTIVE CONTAMINATION OF "BAITEMIR" FIELD

Because no nuclear testing was carried out directly in the minefield, the contamination can be caused only by deposition of radioactive particles on the near trace of a nuclear explosion and global fallout. The fallouts near the epicentre of nuclear tests are coarse particles produced at surface and air explosions and propagate over distances of up to 100 kilometres from the explosion. The global fallouts are caused by fine aerosol particles, long time being in the troposphere and stratosphere.

Surface contamination of the studied area as a result of the former STS may be mainly due to nuclear tests (NT) at "Experimental Field" site, where surface and air nuclear explosions were carried out, since the contribution to environmental contamination (including global scale) from the tunnels and shafts is minimal.

To assess the possible contribution of surface contamination in the studied area as a result of NT, we use a "classical" model of Zones of radioactive trace formation due to a nuclear explosion, which is described in detail in reference [1].

According to the literature, only one nuclear test could affect the radiation environment within "Baitemir" field – a 400 kt ground thermonuclear test carried out on August 12, 1953 (Figure 2).

Testing of 12.08.1953 is a detonation of the thermonuclear device in which a fissile ^{239}Pu appears only as a primer. A thermonuclear fusion is a fusion of two hydrogen isotopes - deuterium and tritium, with release of large amounts of energy. Therefore, the major power of the explosion is due to fusion rather than fission of ^{239}Pu. As a result of the thermonuclear fusion no long-lived radionuclides such as ^{90}Sr and ^{137}Cs are formed. Quantity of activities of residual fissile material remainder and fission fragments in the studied areas are determined only by a mass of the primer. Activation products are not considered in the calculations because of the remoteness of the territory studied from the testing venues.

To determine the mass of ^{239}Pu in the thermonuclear device we estimated content of radionuclide ^{137}Cs in soil samples, taken from the traces of radioactive fallouts, which were formed after the test. The total number of samples amounted to 796 pieces. Average ^{137}Cs activity is 600 Bq/kg. The area of the trace is about 676 km^2, the width at the widest point is approximately 8.7 km. Given the density of soil 1,400 kg/m^3, sampling depth – 0-5 cm and half-life, the average absolute activity of ^{137}Cs in the area of the trace is 774 Ci.

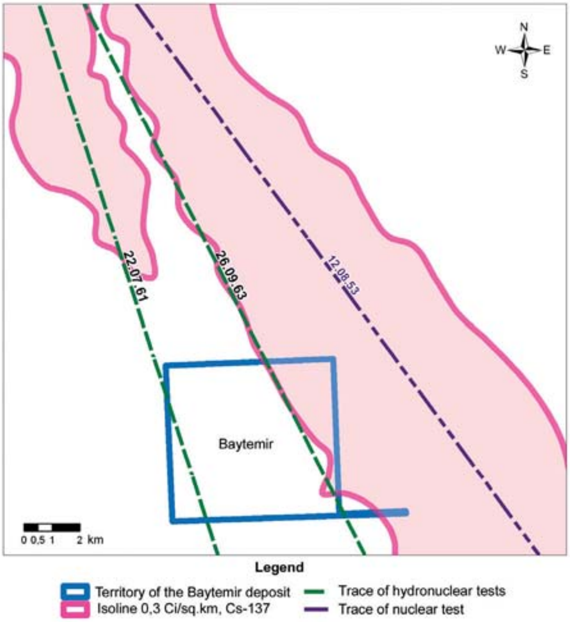


Figure 2. "Baitemir" field and traces (traces axis) of radioactive fallouts

Reference [2] gives the activities of the fission fragments of ^{239}Pu in Ci/km at different moments after the explosion. According to the data, the average absolute activity of ^{137}Cs - 774 Ci corresponds to a 15 kt nuclear explosion.

Also, it needs to be considered that the high-power explosions may raise the explosion cloud into the upper atmosphere. For an explosion of 400 kilotons, the explosion cloud elevation is 20 km, which goes beyond the lower limit of the stratosphere. According to the literature, more than 50% of the activity of the fission fragments is able to go into the atmosphere, which then forms the global fallout. Given the latter, the power of a nuclear explosion, which serves as primer for the thermonuclear reaction, is taken equal to 30 kt.

Based on the dependences of the sizes of radioactive contamination zones on the explosion yield, we calculated the linear sizes of Zones A, B, C, and D for a 400 kt thermonuclear test.

Given the width of the trace, it was determined that Zone B falls into the studied area, the rest of the field is covered with Zone A. Further discussion will be on these types of Zones.

Calculation of the maximal possible "average" concentrations of residual fissile material

The number of remaining at the time of structural failure of the nuclear charge of fissionable material is determined by the efficiency of a nuclear explosion η, which, depending on the type and design of a nuclear device, can range from 1 to 30 percent. For further calculations, in the absence of official data for each explosion, we take it equal to 20%.

For 1 kt explosion with an efficiency η the amount of non-fissile material can be calculated with the formula:

$$N_{RES} = N_f * (1/\eta - 1 - \sigma_{n,\gamma} / \sigma_f),$$

where: $\sigma_{n,\gamma}$,σ_f - radiative-capture cross-section and fission for neutrons in the charge material. For ^{239}Pu the value $\sigma_{n,\gamma}/\sigma_f \approx 0.11$. Knowing the N_{RES} value and the half-life for α-particles ($T_{1/2} = 2.411*10^4$ years for ^{239}Pu), it is easy to calculate the activities of the non-fissile nuclei

$$A(\text{Curie}) = \{N_{RES} * \ln(2)/ T_{1/2}(c)\}/3.7*10^{10}$$

On this basis, per 1 kT of explosion at the time of the explosion after t= 0 we have:

$$A = 13.2 \text{ Ci/kt} = 4.8*10^{11} \text{ Bq/kt for } ^{239}\text{Pu}$$

Further, knowing the typical isotopic composition of weapons-grade Pu, it is simple to calculate the activities of its other isotopes included in the substance of the charge. Thus, we calculated the activity of Pu isotopes with their half-lives for the initial time, to date, and changes in their concentrations after 25 and 50 years have been forecasted. The tables 1 and 2 show the maximal possible "average" activities of Pu isotopes and ^{241}Am in the studied area, as well as their relation to the amount of ^{239}Pu and ^{240}Pu.

Table 1.

Maximal possible "average" activities of Pu isotopes and ^{241}Am in the B Zone

Nuclide	Initial time		1.09.2011		25 years		50 years	
	Bq/kg	Relation	Bq/kg	Relation	Bq/kg	Relation	Bq/kg	Relation
^{239}Pu + ^{240}Pu	7.9	1	7.9	1	7.9	1	7.8	1
^{238}Pu	0.26	0.033	0.17	0.022	0.14	0.018	0.11	0.014
^{241}Pu	66	8.4	4.1	0.52	1.2	0.15	0.37	0.047
^{242}Pu	1.1×10^{-5}	1.4×10^{-6}	1.1×10^{-5}	1.4×10^{-6}	1.1×10^{-5}	1.4×10^{-6}	1.1×10^{-5}	1.4×10^{-6}
^{241}Am	-	-	2.1	0.266	2.2	0.28	2.2	0.28

Table 2.

Maximal possible "average" activities of Pu isotopes and ^{241}Am in the A Zone

Nuclide	Initial time		1.09.2011		25 years		50 years	
	Bq/kg	Relation	Bq/kg	Relation		Bq/kg	Relation	Bq/kg
^{239}Pu + ^{240}Pu	0.125	1	0.125	1	0.125	1	0.125	1
^{238}Pu	4.2×10^{-3}	0.032	2.7×10^{-3}	0.021	2.2×10^{-3}	0.017	1.8×10^{-3}	0.014
^{241}Pu	1.1	8.5	6.5×10^{-2}	0.5	1.9×10^{-2}	0.15	5.8×10^{-3}	0.046
^{242}Pu	1.8×10^{-7}	1.4×10^{-6}	1.8×10^{-7}	1.4×10^{-6}	1.8×10^{-7}	1.4×10^{-6}	1.8×10^{-7}	1.4×10^{-6}
^{241}Am	-	-	0.033	0.25	0.0344	0.28	0.0349	0.28

De facto the ^{241}Pu activity may be somewhat higher due to ^{240}Pu activation by prompt neutrons, but cross section for this reaction is very little to make a significant contribution.

2. RADIOECOLOGICAL SITUATION AT "BAITEMIR" FIELD

2.1. Generic survey procedure

Based on the information about the passage of radioactive fallout traces, the territory was surveyed on the profiles that are located across the axis of the trace from the test dated 12.08.1953 (Figure 3). To assess the impact of radioactive contamination of the nearby areas on the formation of radiation situation in "Baitemir" field, the research was conducted outside of it.

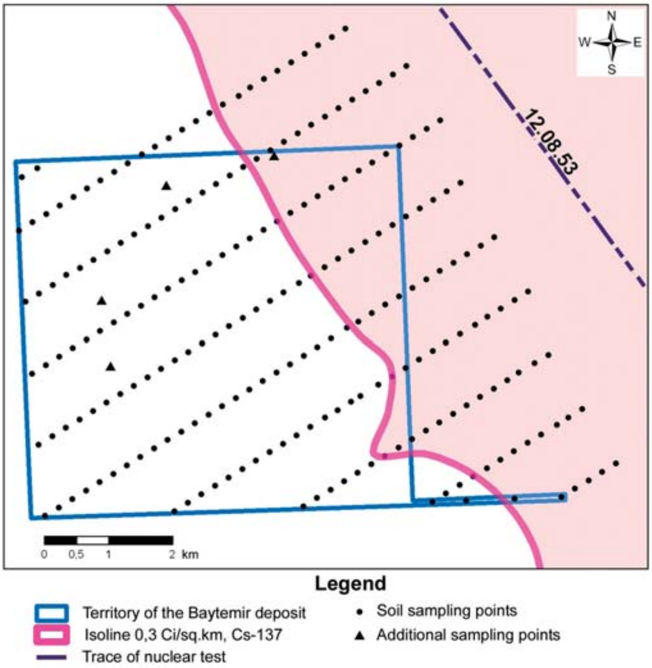


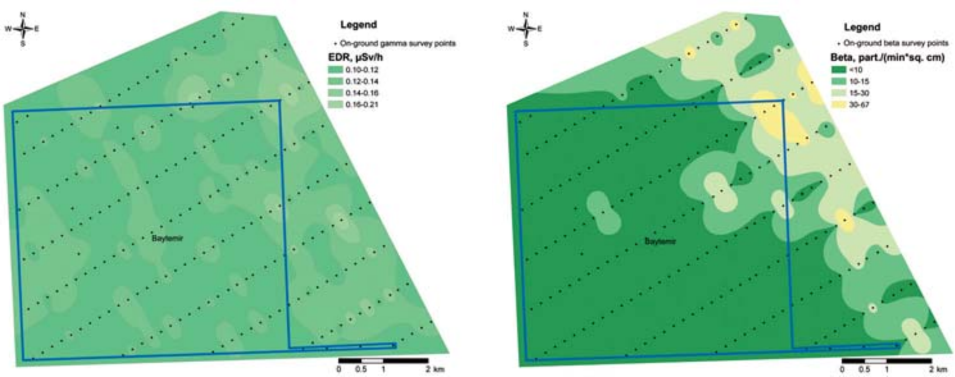
Figure 3. Examination within "Baitemir" field

Conducting radiological surveys within "Baitemir" field included:

- a breakdown of survey points in the studied area using a GPS receiver;
- pedestrian gamma-, beta-survey in 250×1000 m network;
- soil sampling at the points evenly distributed on the survey site, and at the points with the highest values of radiation parameters;
- sampling of bottom sediments;
- sampling of air aerosols.

Integral radiation parameters

Total during the survey 222 points were measured for radiation parameters. The average density of the survey was 1 measurement per 0.25 km^2. Equivalent dose rate (EDR) at a height of 0.03 m above the ground surface and the flux density of β-particles were measured during the sampling. Distribution of EDR (at a height of 0.03 m) and the flux density of β-particles in the studied area are presented in the maps (Figure 4).



a) b)

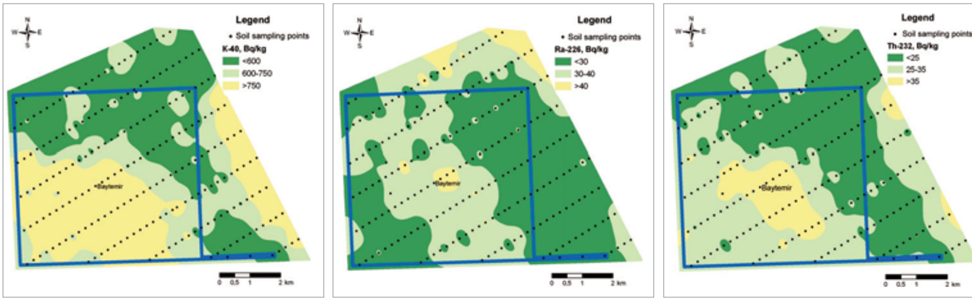
Figure 4. Distribution of radiation parameters (EDR, flux density of β-particles) in the surveyed area

EDR at the points of soil sampling within the surveyed area was in the range <0.1-0.21 μSv/h, the arithmetic mean value was 0.12 μSv/h (for comparison, in the "northern" and "western" parts of STS the average EDR were 0.12 and 0.11 μSv/h, respectively). The flux density of β-particles ranged from <10 to 67 particles/(min*cm^2). Most of the measured values (85%) is below the detection limit of used measuring tools (10 particles/(min*cm^2)). The arithmetic mean value was 25 particles/(min*cm^2). Thus, the field radiometric studies have established that part of the surveyed area, were higher values of EDR (higher than 0.16 μSv/h) and the flux density of β-particles were recorded (more than 10 particles/(min*cm^2)), is located within the path of radioactive fallout from the thermonuclear test (12.08.1953).

2.2. Distribution of natural and artificial radionuclides within the soil cover

2.2.1. Areal distribution of natural radionuclides

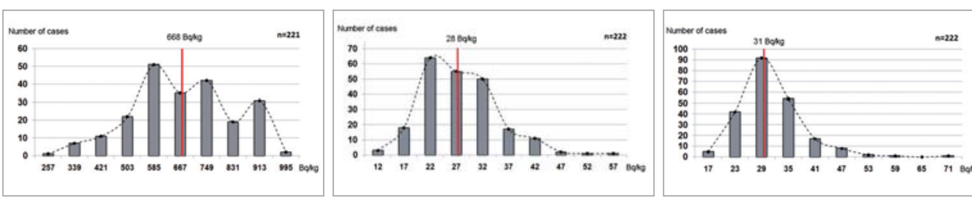
One of the components of the radiation background in the studied area is due to natural radionuclides, which are included in the decay series of uranium, thorium and potassium (^{40}K). Of natural radionuclides we determined ^{40}K, ^{232}Th and ^{226}Ra. Natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra were determined in 222 soil samples taken from 0–5 cm surface horizon. Based on the survey, we built areal distribution maps of specific activities for ^{40}K, ^{232}Th and ^{226}Ra (Figure 5).



a) b) c)

Figure 5. Distribution of ^{40}K, ^{226}Ra, ^{232}Th specific activities in the soil of "Baitemir" field

Distribution of the specific activities for natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra is shown in histograms (Figure 6).



a) b) c)

Figure 6. Specific activity distribution in soils for ^{40}K (a), ^{232}Th (b), ^{226}Ra (c)

Analyzing the results, the following conclusions can be made. Distribution of ^{40}K radionuclide obeys the logarithmically normal distribution law - "three-hump distribution". Distribution of ^{226}Ra and ^{232}Th radionuclides also obeys lognormal distribution law with right asymmetry.

In the studied area the maximal specific activities of natural radionuclides were as follows: for ^{40}K – 970, ^{226}Ra – 73, ^{232}Th – 55 Bq/kg.

To compare the results, Table 3 shows the maximal and minimal specific activities of natural radionuclides in soils of Kazakhstan, as well as their averages [3].

Table 3.

Activity of natural radionuclides in soils of Kazakhstan

Variation limits	Specific activity, Bq/kg		
	^{40}K	^{226}Ra (^{238}U)	^{232}Th
Minimal values	100	12	10
Maximal values	1200	120	220
Average	300	37	60
Surveyed area	970	73	55
Note: It is assumed that in the ores of uranium and thorium, radioactive equilibrium is close to unity, specific activity of uranium and radium is equal			

Recorded maximal specific activities of ^{40}K, ^{226}Ra and ^{232}Th in the samples taken from the studied area do not exceed the maximal numbers for soils of Kazakhstan.

2.2.2. Areal distribution of artificial radionuclides

^{137}Cs contamination in the studied area

Number of the tested samples – 222. A map of ^{137}Cs areal distribution was built based on the studies (Figure 7).

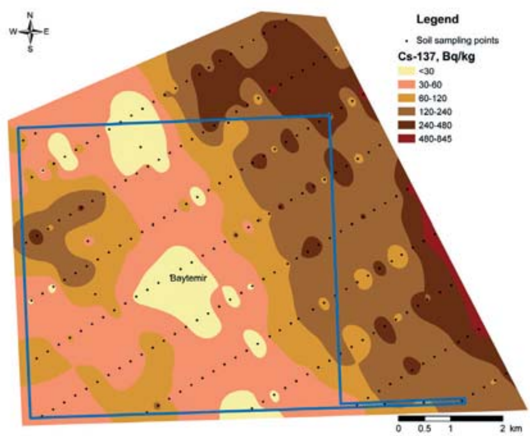


Figure 7. Distribution of ^{137}Cs specific activity in soils of "Baitemir" field

The range of specific activity is from 1 to 876 Bq/kg, with an average of 147 Bq/kg (red line in Figure 8). Thus the basic data set is in the range up to 600 Bq/kg, whereas the mean value is 144 Bq/kg. The histogram (Figure 8) shows that the distribution of frequency of points with certain values of the specific activity has the distribution pattern close to the lognormal distribution.

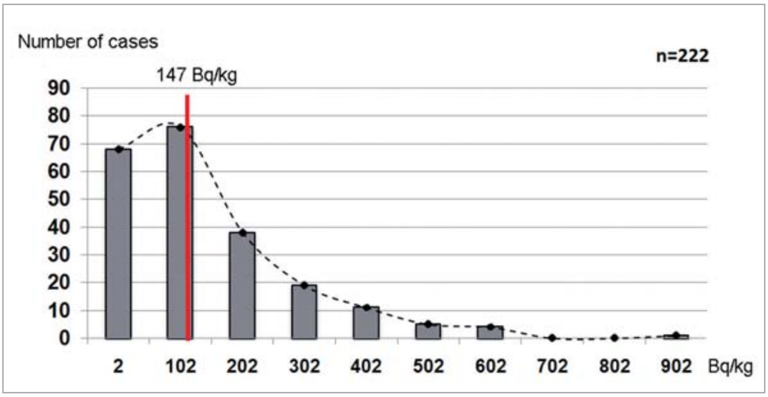


Figure 8. Distribution of ^{137}Cs specific activity values in soils

The average specific activity of ^{137}Cs in this area 5 times exceeds the maximal for the background of global fallout for this radionuclide (30 Bq/kg). The elevated specific activity of ^{137}Cs in soils is confined to the traces of the radioactive fallout from nuclear testing traces (Figures 2, 7).

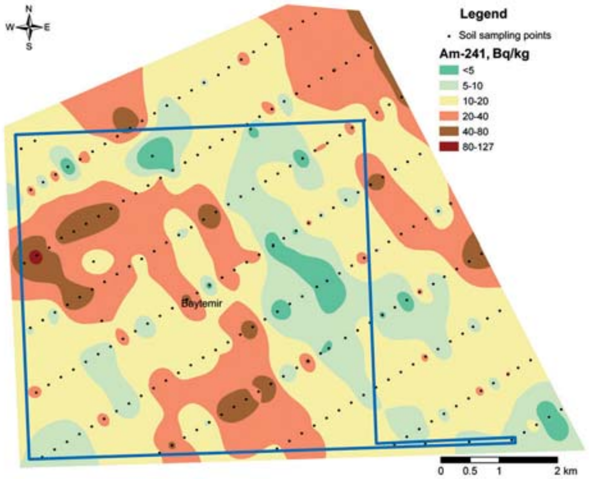


Figure 9. Distribution of ^{241}Am specific activity in soils of "Baitemir" field

Contamination of the studied area with ^{241}Am

Based on the studies, a map of ^{241}Am areal distribution was built (Figure 9).

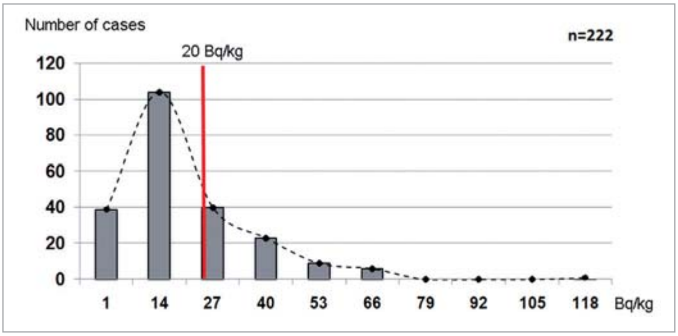


Figure 10. Distribution of ^{241}Am specific activity in soils

The activity ranges from <0.74 to 113 Bq/kg with a mean of 20 Bq/kg. Thus the basic data set is in the range up to 68 Bq/kg. The histogram shows that the distribution of frequency of points with certain specific activity has a distribution pattern close to the lognormal distribution (Figure 10). The higher values of ^{241}Am specific activity in soils coincide with Zones with higher concentration of ^{137}Cs and are confined to the radioactive fallout traces (Figures 2, 7, 9).

$^{239+240}Pu$ contamination in studied area

Given the considerable complexity of the conventional method for determining $^{239+240}Pu$ (alpha spectrometry with preliminary radiochemical separation), in this study of plutonium contamination we were methodologically focused on the identification of a correlation between ^{241}Am and plutonium. This approach is quite common and quite reasonable.

Based on the studies, a histogram of $^{239+240}Pu/^{241}Am$ ratio was built (Figure 11). To determine the ratio $^{239+240}Pu/^{241}Am$, the soil samples were prepared in a special way (preparation procedure consisted of several stages of attrition), the quality was controlled by the content of ^{241}Am in the aliquot samples. Concentration of ^{241}Am was determined as the mean of three measurements of these samples.

The average ratio $^{239+240}Pu/^{241}Am$ was found to be 10.8, which is quite close to the expected value; the correlation coefficient was significant comprising 0.64 (total number of samples – 21).

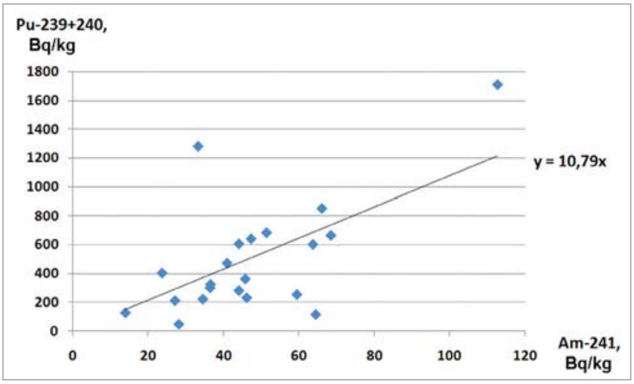


Figure 11. Ratio of $^{239+240}Pu$ and ^{241}Am specific activity in soil samples

Thus, the contamination with plutonium isotopes correlates with americium contamination; average concentration of $^{239+240}Pu$ amounted to 215 Bq/kg.

Based on the studies, a map of $^{239+240}Pu$ point distribution was built (Figure 12).

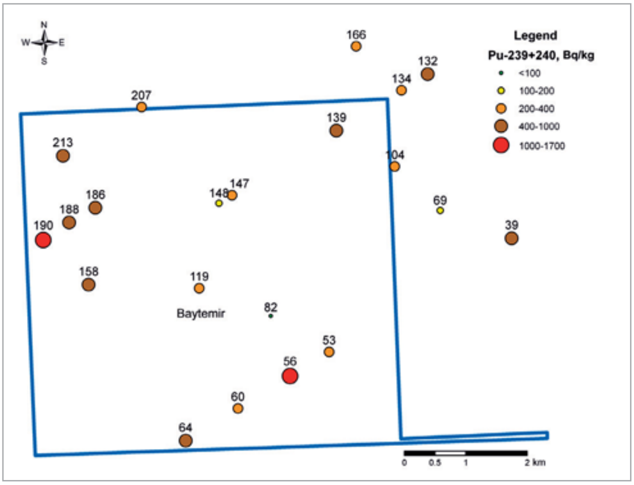


Figure 12. Distribution of $^{239+240}Pu$ specific activity in soils

Higher values of $^{239+240}Pu$ specific activity in soils are confined to the traces of the radioactive fallout from nuclear and hydronuclear tests (Figures 2, 12).

$^{238}Pu/^{239+240}Pu$ specific activity ratio is shown in Figure 13.

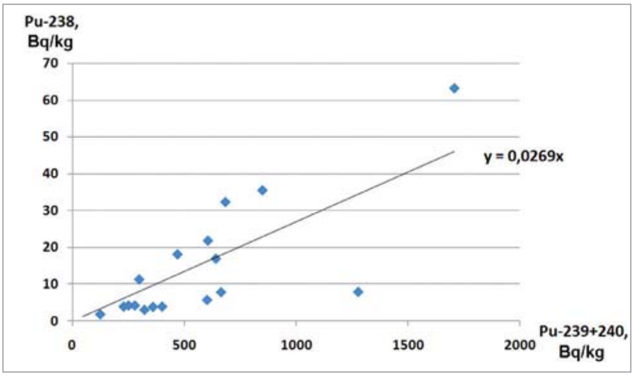


Figure 13. ^{238}Pu and $^{239+240}Pu$ ratio in soil samples

Thus, the average ratio of $^{238}Pu/^{239+240}Pu$ was 0.03; mean specific activity of ^{238}Pu – 6.4 Bq/kg.

^{90}Sr contamination in the studied area

^{90}Sr was measured in two ways: first, the samples were analyzed instrumentally with the beta-spectrometer "Progress", a radiochemical separation method was used for more detailed research. The maximal specific activity was 7,000 Bq/kg.

Based on the studies, a distribution map for ^{90}Sr specific activity was built (Figure 14).

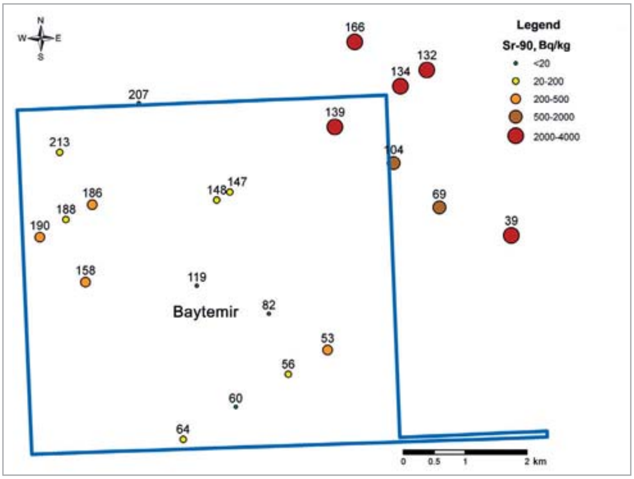


Figure 14. Distribution of ^{90}Sr specific activity in soils (results of 2010)

Histogram of the lognormal distribution of frequency of points with certain ^{90}Sr specific activity is shown in Figure 15.

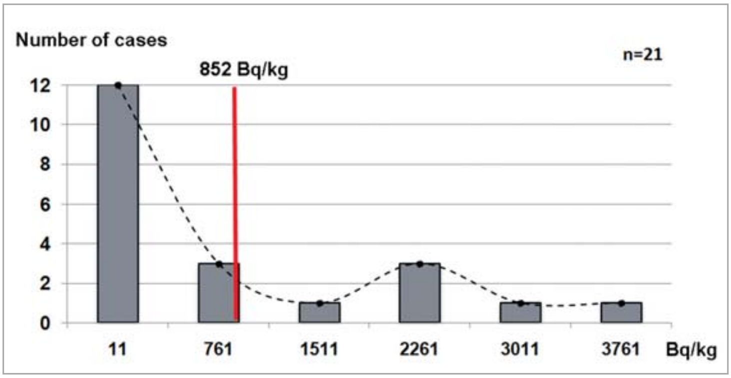


Figure 15. Distribution of ^{90}Sr specific activity values in soils

The average ^{90}Sr specific activity was taken to be 850 Bq/kg, which 45 times exceeds the background of global fallouts (18 Bq/kg). Higher values of ^{90}Sr specific activity in soils are confined to the traces of the radioactive fallouts from nuclear testing traces (Figures 2, 14).

Contamination in studied area with other radionuclides

We also studied such artificial radionuclides as ^{60}Co, ^{152}Eu, ^{154}Eu (except for ^{137}Cs and ^{241}Am) in the soil samples employing gamma-ray spectral analysis; maximal contents were: ^{60}Co – 2.8, ^{152}Eu – 49.4 and ^{154}Eu – 6.4 Bq/kg, respectively. Maps of areal ^{60}Co, ^{152}Eu distribution were built (Figure 16). Contamination of this territory with radionuclides is due to the fallout from the testing of the first thermonuclear device (12.08.1953)

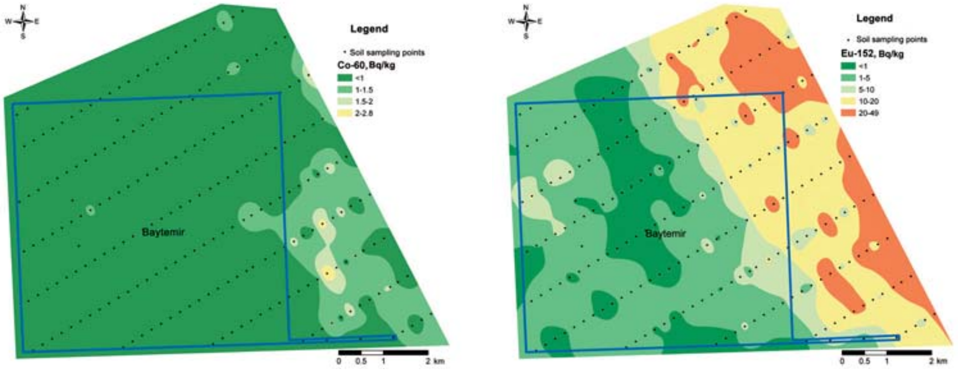


Figure 16. Distribution of ^{60}Co and ^{152}Eu specific activities in soils of "Baitemir" field

Specific activities of other radionuclides, such as ^{151}Sm, ^{99}Tc, which have not been determined experimentally, but whose presence is expected, were determined by theoretical calculations based on the average specific activity of ^{137}Cs and theoretical ratio of these isotopes. The following average values of specific activity for the calculations were taken: for ^{151}Sm – 12. ^{99}Tc – 2.35 Bq/kg.

Distribution of ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}Pu$ radionuclides in the studied area can single out several Zones with different structures and levels of radioactive contamination generated by various sources (hydronuclear and thermonuclear tests).

To identify the areas with high specific activities of artificial radionuclides there was used a method for plotting the distribution of specific activities of ^{137}Cs and ^{241}Am along the profiles, previously used in the analysis of the "northern" and "western" parts of STS. The profiles are presented in Figure 17.

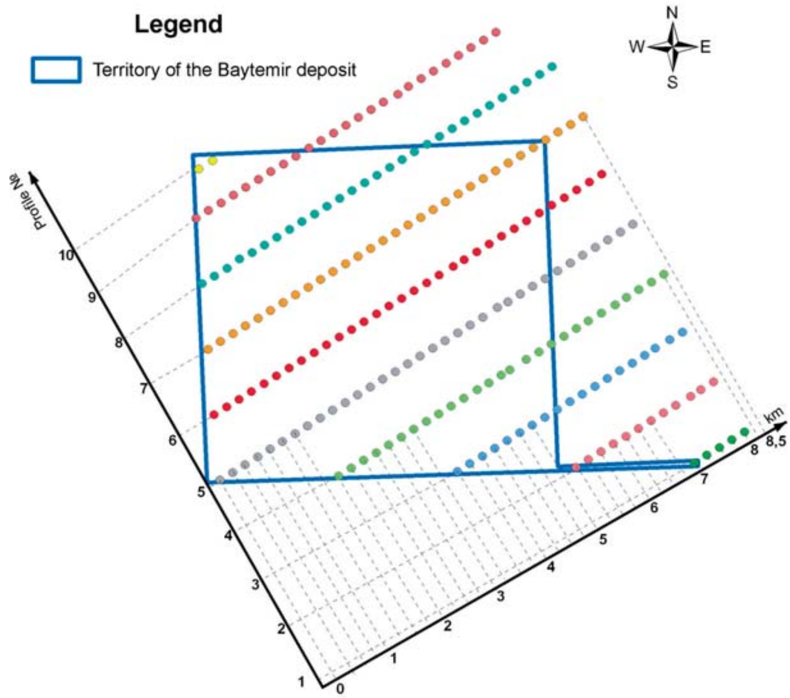
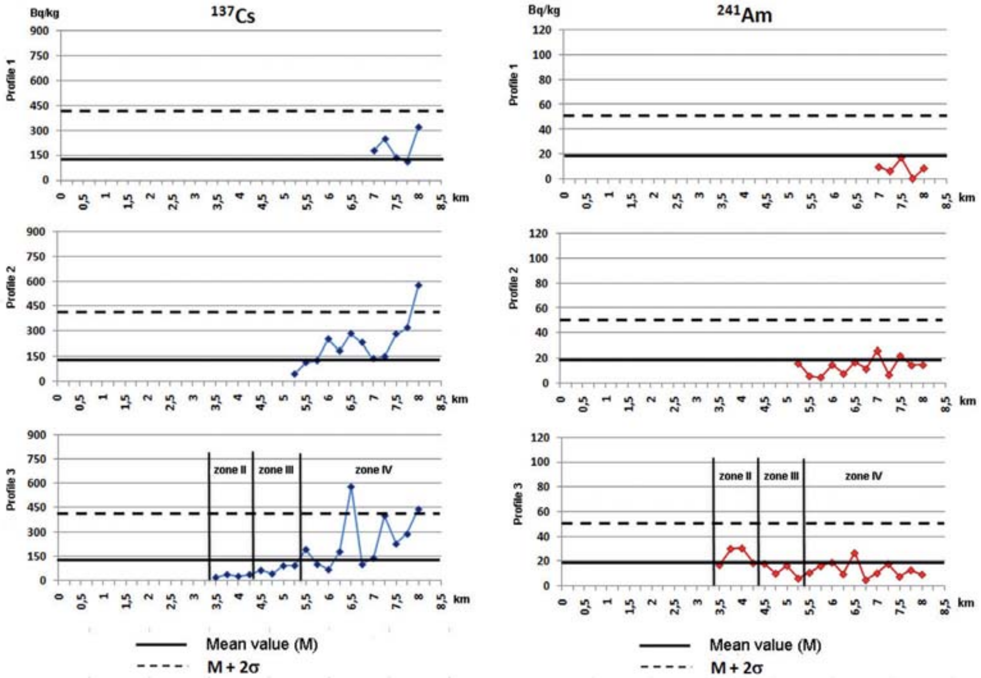
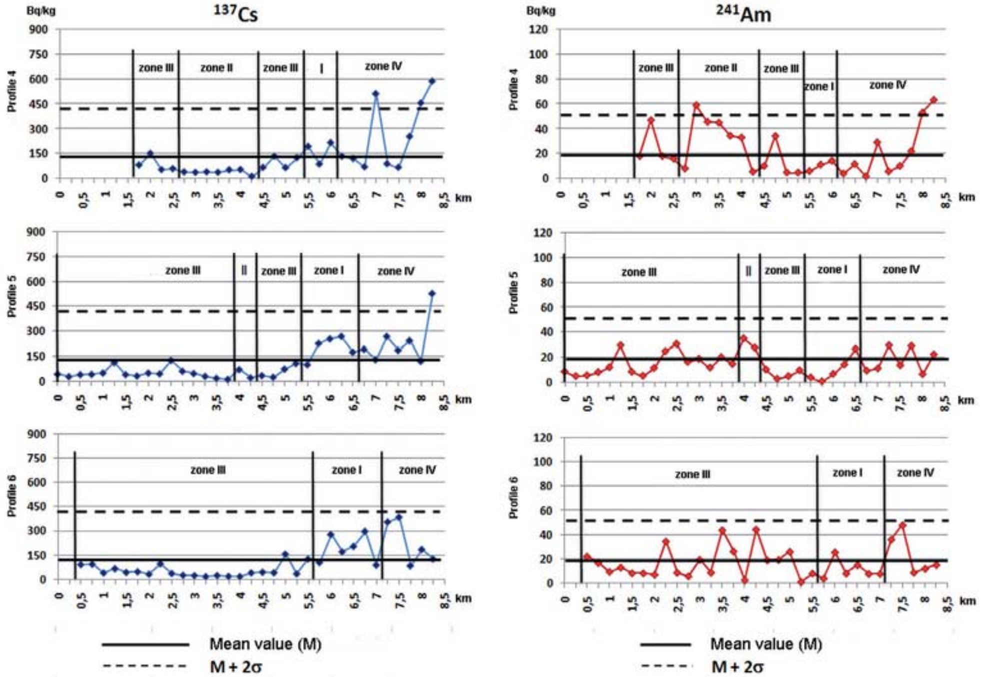


Figure 17. Profiles outline

For each profile, distributions of ^{137}Cs and ^{241}Am specific activities were built (Figure 18).

Distribution of ^{241}Am and ^{137}Cs radionuclides can be divided into two Zones (I and II), where their higher specific activities in the soil cover were recorded, and a Zone with relatively low values (III). Also the graphs highlight Zone IV, located outside of "Baitemir" field, where higher contents of radionuclides ^{241}Am and ^{137}Cs were recorded. This pattern is clearly visible in the graphs on profiles 7 and 8 (Figure 18).


Bq/kg
137Cs
241Am
Profile 1
Profile 2
Profile 3
km
zone II
zone III
zone IV
Mean value (M)
M + 2σ


Bq/kg
137Cs
241Am
Profile 4
Profile 5
Profile 6
km
zone I
zone II
zone III
zone IV
I
II
Mean value (M)
M + 2σ

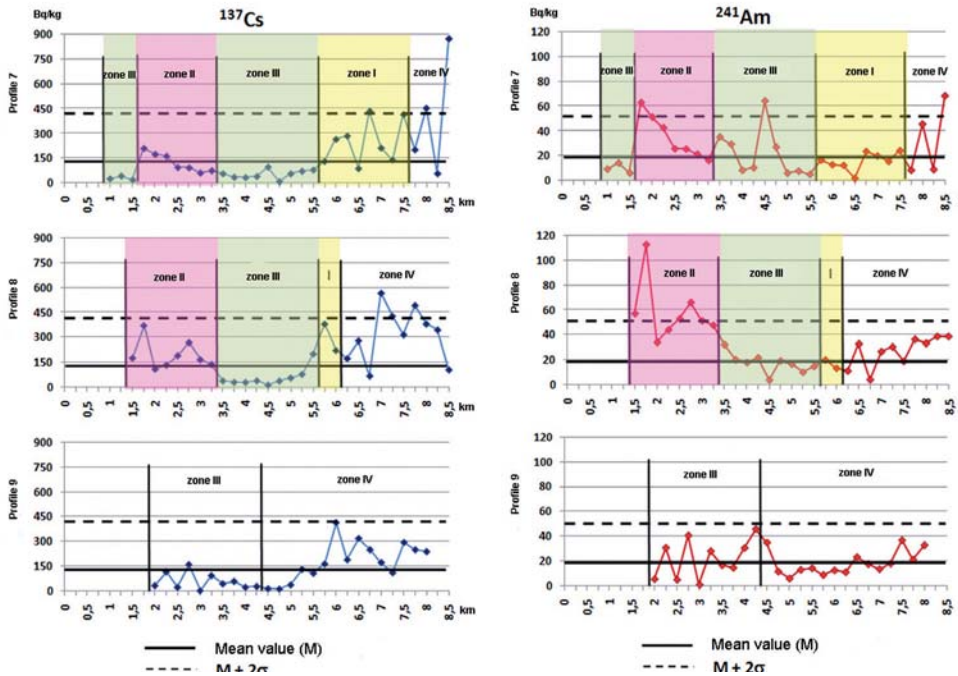


Figure 18. ^{137}Cs and ^{241}Am specific activities along the profiles

These Zones are marked on the results from the study of artificial radionuclides areal distribution. Location of Zones is shown on the map of ^{137}Cs distribution (Figure 19).

When singling out the areas we took into account the conformity of the territory with high values and specific activities of radionuclides to the area which radioactive clouds possibly passed over.

Determination of average specific activity

To calculate the average specific activity of artificial radionuclides in the Zones, the following sequence of actions was performed.

The entire data set was divided into three Zones. For each Zone we calculated the specific activity ratios for the radionuclides ^{90}Sr and ^{137}Cs, $^{239+240}$Pu and ^{241}Am (Figure 20), ^{238}Pu and $^{239+240}$Pu.

The map of ^{90}Sr/^{137}Cs distribution shows the sections with higher values corresponding to the thermonuclear fallout from 12.08.1953, $^{239+240}$Pu/^{241}Am distribution – higher values corresponding to the hydronuclear traces from 22.07.1961.

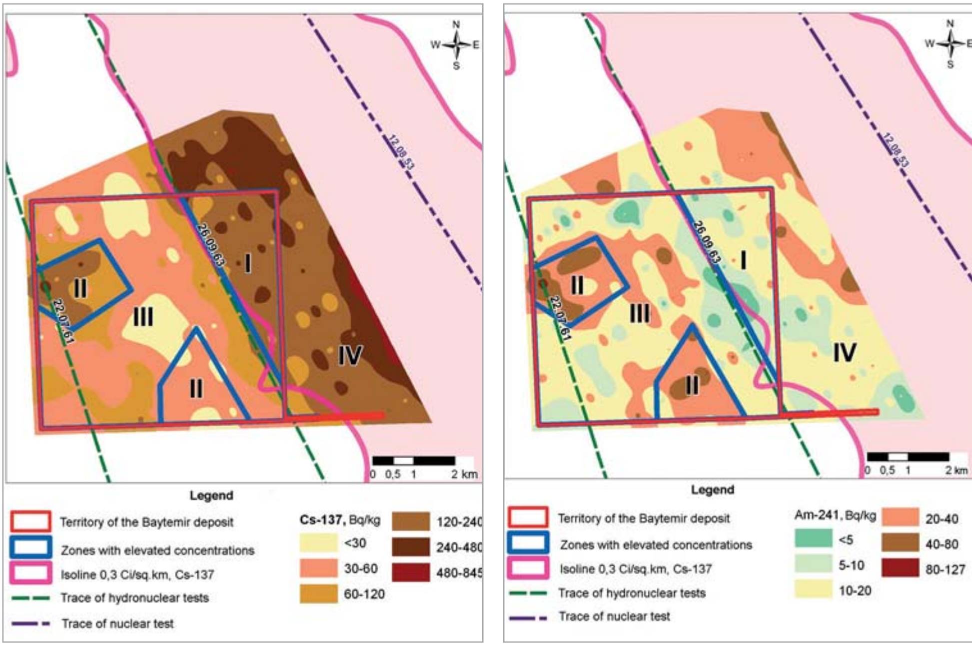


Figure 19. Distribution of Zones with different levels of ^{137}Cs and ^{241}Am specific activities

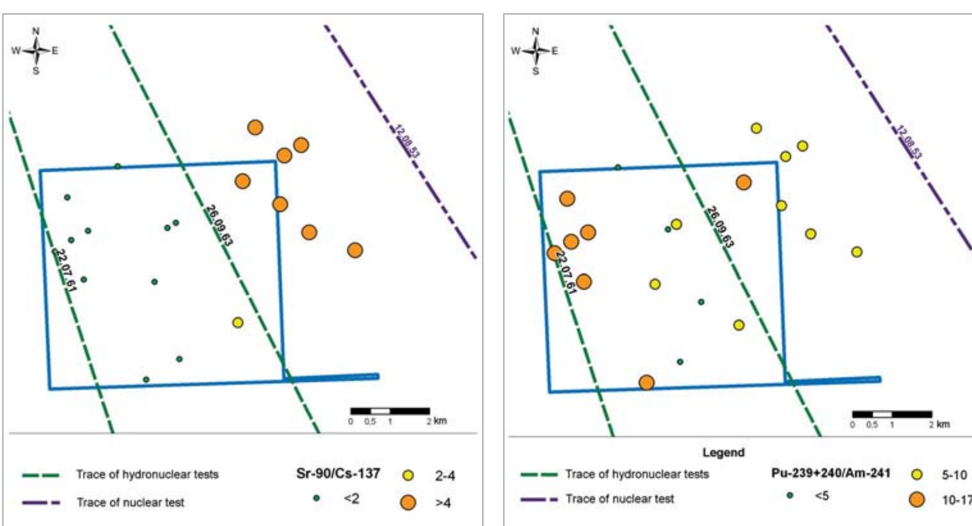


Figure 20. Distribution of the specific activities ratios for ^{90}Sr and ^{137}Cs, $^{239+240}Pu$ and ^{241}Am in "Baitemir" field

Then we built graphs of the radionuclides ratios in each Zone, including the values, which clearly belong to this totality, but not included in the contour line of the Zone due to low specific activity, and calculated a ratio of radionuclides within the Zones (Figure 21-23).

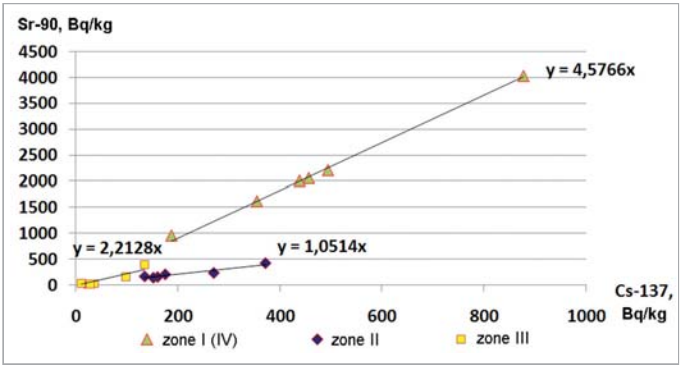


Figure 21. Ratio of ^{90}Sr and ^{137}Cs specific activities in the Zones

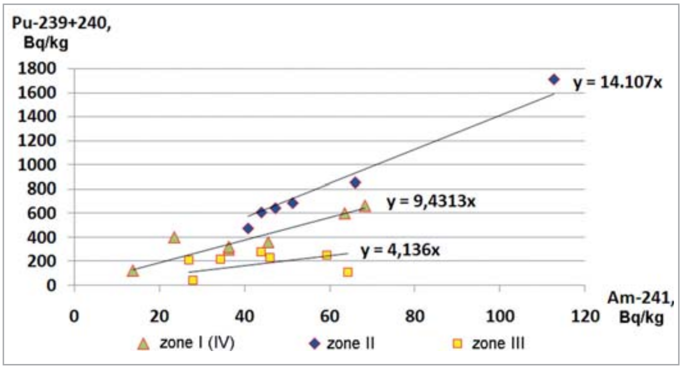


Figure 22. Ratio of $^{239+240}$Pu and ^{241}Am specific activities in the Zones

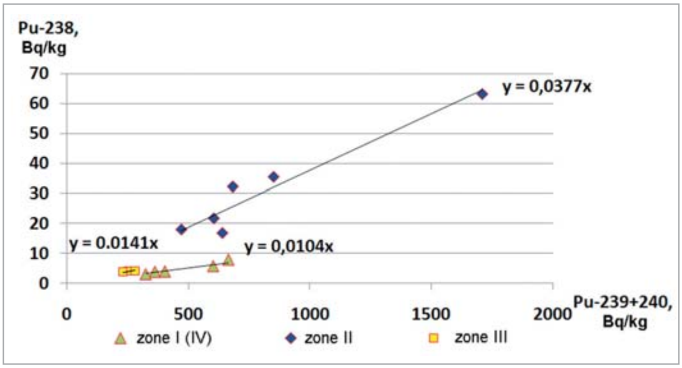


Figure 23. Ratio of ^{238}Pu and $^{239+240}$Pu specific activities in the Zones

The obtained values of the ratios of radionuclides have been tabulated for the calculation of average values of ^{90}Sr, $^{239+240}Pu$, ^{238}Pu based on the known average specific activities of ^{137}Cs and ^{241}Am (Table 4).

Table 4.

Ratios of radionuclides within the designated Zones

	$^{90}Sr/^{137}Cs$	$^{239+240}Pu/^{241}Am$	$^{238}Pu/^{239+240}Pu$
Zone I(IV)	4.58	9.43	0.01
Zone II	1.05	14.11	0.04
Zone III	2.21	4.14	0.01

For singled out Zones there were calculated mean values of artificial radionuclides specific activity that were used for further calculations of dose rates (Table 5).

Table 5.

Average specific activities of artificial radionuclides in Zones, Bq/kg

^{137}Cs	^{152}Eu	^{90}Sr	^{241}Pu	^{238}Pu	^{241}Am	$^{239+240}Pu$	^{99}Tc	^{151}Sm
Zone I								
212	15	972	30.4	1.2	12.7	119.5	3.4	17
Zone II								
105	2.7	111	94	21	39	551	1.7	8.4
Zone III								
58.4	2	129	39.6	6.4	16.5	68	0.9	4.7

2.4. Soil cover

The ranges in the area under study show little or no signs of overgrazing, and the soils are not affected, or slightly affected by wind erosion.

Radioactive contamination of soils

The radioactive contamination mostly affected underdeveloped and poorly developed light brown soils on the tops of hills in the north-west and north-east of the area. Contamination was caused by the fallouts from the radioactive clouds, so it appears in small spots. Based on the available material, a detailed study of similar situations in the same natural area, in the northern and western parts of the STS territory, we can say that the penetration of radionuclides into the soil at fallout areas would be limited for ^{137}Cs to surface horizon of 0-5, 5-10 cm, ^{241}Am and $^{239+240}Pu$ can penetrate into 2-5 cm deep, and only ^{90}Sr, in view of the considerable solubility and mobility, can penetrate 20-30 cm deep.

Distribution of radionuclides in the depth of the soil profile

To obtain indicators that characterize the studied area, we laid soil profiles in 3 test areas located in different parts of the relief and at different elevations (Figure 24).

Within these test areas are the highest values of ^{241}Am, ^{137}Cs, ^{90}Sr or $^{239+240}Pu$ specific activities. The soil profiles were laid at points ## 56, 139, 190 (Figure 24). Soil was sampled in layers with an interval of 3 cm to 30 cm depth and then by 5 cm to 50 cm depth. The data obtained on ^{241}Am and ^{137}Cs contents are shown in Table 6 and Figure 25.

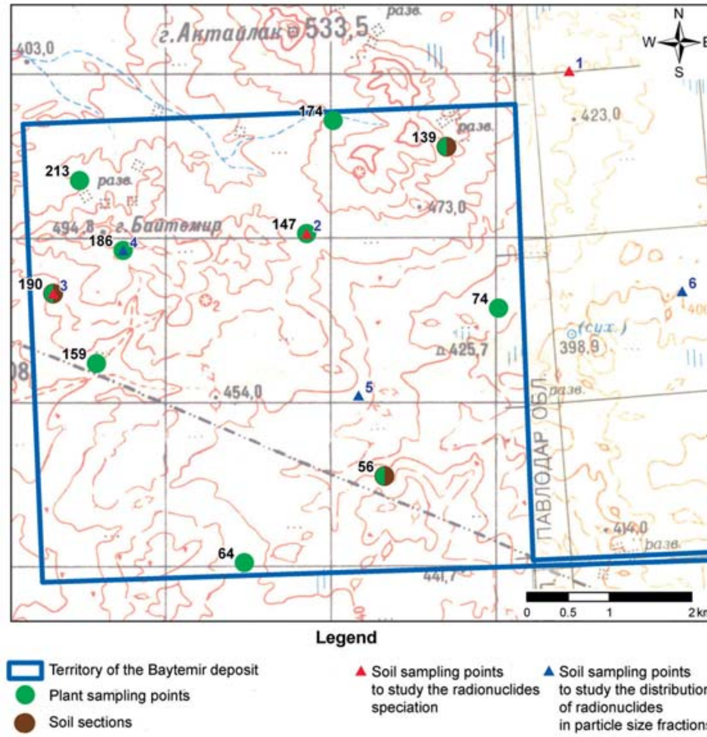
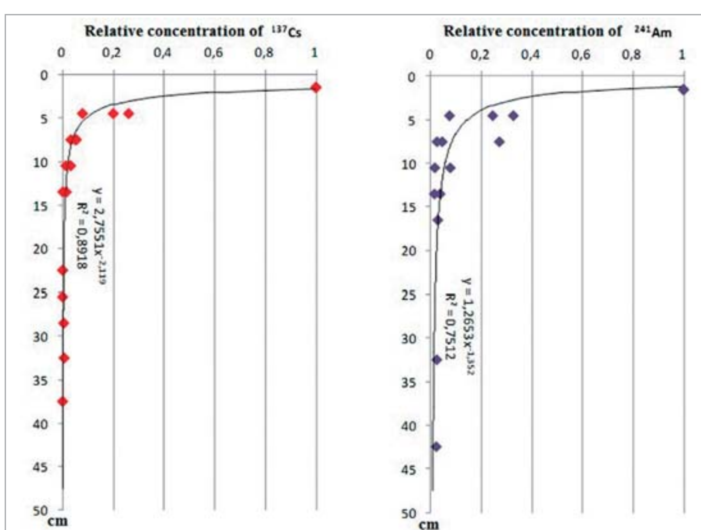


Figure 24. Layout of soil and plants sampling points



a) b)

Figure 25. Distribution of ^{241}Am and ^{137}Cs radionuclides in the soil of "Baitemir" field as a fraction of maximal concentration

Table 6.

Content of radionuclides ^{241}Am and ^{137}Cs in the soils "Baitemir" field

Sampling depth, cm	Section 56		Section 139		Section 190	
	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{241}Am, Bq/kg	^{137}Cs, Bq/kg
0-3	11.1 ± 0.69	44.0 ± 1.77	41.4 ± 1.02	532 ± 4.6	26.3 ± 0.75	93.2 ± 1.81
3-6	<0.81	3.50 ± 0.76	10.1 ± 0.55	107 ± 2.1	8.57 ± 0.49	24.4 ± 0.98
6-9	3.00 ± 0.51	1.49 ± 0.63	0.97 ± 0.30	26.9 ± 1.1	1.16 ± 0.30	5.20 ± 0.52
9-12	<0.84	< 0.79	0.60 ± 0.28	17.6 ± 0.9	< 0.43	1.33 ± 0.35
12-15	< 0.62	< 0.75	<0.55	1.09 ± 0.34	0.93 ± 0.42	1.45 ± 0.65
15-18	< 0.67	< 0.63	< 0.40	< 0.46	<0.69	< 0.93
18-21	< 0.61	< 0.74	< 0.45	< 0.44	< 0.40	< 0.46
21-24	< 0.63	< 0.82	< 0.39	<0.67	< 0.43	< 0.40
24-27	< 0.43	< 0.43	< 0.42	<0.52	< 0.46	< 0.37
27-30	< 0.42	< 0.40	< 0.55	< 0.89	< 0.46	<0.53
30-35	< 0.40	< 0.44	< 0.42	< 0.45	<0.60	<0.66
35-40	< 0.42	< 0.47	< 0.44	<0.57	< 0.46	< 0.43
40-45	< 0.47	< 0.46	< 0.40	< 0.43	<0.54	< 0.38
45-50	< 0.45	< 0.52	< 0.41	< 0.41	< 0.43	< 0.44

Distribution of ^{241}Am and ^{137}Cs in the soil profile of 3 sections, as was expected, obeys certain regularities in the distribution of radionuclides in arid dry steppe or desert subzones, where soil is moisturized by precipitation and no additional sources. Maximal and major content of these radionuclides are observed in the surface horizons to a depth of 10 cm (Figure 25). Further down the profile the values are plummeting, and recorded at the lower limits of the measurement tools.

In general, the nature of ^{137}Cs distribution in all three sections is similar. Figure 25 (a) shows the distribution of ^{137}Cs radionuclide in "Baitemir" field soil expressed as a fraction of the maximal concentration, reconstructed on the basis of data on three sections. No data spread is observed. The same is observed for ^{241}Am (Figure 25. b). It should be noted, the distribution of ^{241}Am and ^{137}Cs is similarly independent on the micro-relief (section 139 is in inter-low-hill hollow, section 190 – at the top of the hill slope, and section 56 – at gentle inter-low-hill plain), as well as the subtype of soils. Thus, soil profiles 139 and 190 can be attributed to chestnut, and soil profile 56 – to light chestnut.

2.5. Vegetation cover

To determine the nature of vegetation contamination with artificial radionuclides in the studied area, the levels and parameters of ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am and ^{152}Eu transfer from soil to plants were analyzed. For this purpose, like for the natural radionuclides we used [4] and experimental [1, 5] data on the average accumulation factors (AF).

Additionally there were expeditions for sampling of soils and plants for further determination of specific activity and calculation of accumulation factors for the radionuclides ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, ^{241}Am and ^{152}Eu. For this purposes, in areas with high specific activities of these radionuclides in soil, established by areal survey, 10 research sites were incorporated (sampling points) located in 3 Zones with different radioactive contamination (Figure 24).

At each site combined soils samples were taken (by "envelope" (2 × 1 m) method to a depth of 5 cm) and above-ground parts of plants (sampling area ~2 square meters), represented by combined samples of steppe motley grasses with domination of feather grass (*Stipacapillata*, *S. sareptana*, *S. lessingiana*), fescue grass (*Festuca valesiaca*) and wormwood (*Artemisia gracileccens, A. frigida*).

The obtained specific activities and AF of ^{137}Cs, ^{241}Am and ^{152}Eu radionuclides are shown in Table 7.

Table 7.

Specific activities and AF of ^{137}Cs, ^{241}Am and ^{152}Eu radionuclides

##	Point	Specific activity, Bq/kg						AF		
		^{241}Am		^{137}Cs		^{152}Eu		^{241}Am	^{137}Cs	^{152}Eu
		plant	soil	plant	soil	plant	soil			
1	139	<0.23	24.0±1.1	0.89±0.46	476±6	<0.20	34.3±0.9	<0.0096	0.0019	<0.0058
2	56	0.88±0.21	15.6±0.8	<1.00	24.2±1.4	<0.30	1.3±0.3	0.056	<0.041	<0.23
3	64	1.01±0.08	58.0±1.3	6.2±0.3	138±3	<0.10	3.7±0.4	0.017	0.045	<0.027
4	213	0.28±0.17	24.4±0.7	<0.89	107±2	<0.34	1.9±0.3	0.012	<0.0083	<0.18
5	186	0.21±0.12	56.9±1.4	1.6±0.3	187±4	<0.29	7.1±0.5	0.0037	0.0086	<0.041
6	159	<0.23	40.4±0.9	2.6±0.3	118±2	0.75±0.24	2.7±0.4	<0.0057	0.022	0.28
7	74	0.89±0.32	9.0±0.7	1.5±0.5	166±3	<0.88	10.4±0.5	0.099	0.0088	<0.085
8	174	<0.48	19.4±0.9	1.8±0.5	374±6	<0.65	25.5±0.8	<0.025	0.0047	<0.025
9	147	<0.30	14.7±0.8	2.5±0.4	57.3±2.2	<0.40	3.7±0.4	<0.020	0.044	<0.11
10	190	<0.23	34.8±0.9	0.42±0.23	136±2	<0.32	3.6±0.4	<0.0066	0.0031	<0.089

The analysis revealed that the maximal ^{137}Cs specific activity in plants in the territory of "Baitemir" field does not exceed ~ 6 Bq/kg, ^{241}Am - ~1 Bq/kg, ^{152}Eu -~ 0.75 Bq/kg.

In this paper we took as average ^{137}Cs and $^{239+240}$Pu accumulation factors the values based on the experimental data obtained for the steppe motley grasses in the "western" territories of the STS [5], ^{90}Sr – "northern" territories of the STS [1], ^{152}Eu – for one of the dominant species of steppe vegetation (feather grass (*Stipacapillata*)) in the territory of "Experimental Field" site of the STS. Average ^{241}Am and ^{152}Eu accumulation factors are selected on the basis of the IAEA (2009) [4]. Given the accepted AF and average specific activities (SA) of radionuclides in the soil, average contents of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, ^{241}Am and ^{152}Eu in plants were calculated (Table 8).

Table 8.

Assessment of artificial radionuclides in plants in the studied area

Average values	Radionuclide specific activity, Bq/kg				
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am	^{152}Eu
Ac	0.05	0.7	0.04	0.01	-
Zone I - Average SA in soil, Bq/kg	186	-	132	11.3	12.2
Zone II - Average SA in soil, Bq/kg	136	258	491	41.9	3.4
Zone III - Average SA in soil, Bq/kg	54.2	114	390	18.4	1.8
Zone I - Calculated SA in plants, Bq/kg	9.3	-	5.3	0.11	-
Zone II - Calculated SA in plants, Bq/kg	6.8	180	19.6	0.42	-
Zone III - Calculated SA in plants, Bq/kg	0.3	7.6	15.6	0.18	-
Allowable levels in plants, Bq/kg	74	111	~10*	~10*	~100*
Note: * - estimated allowable levels, see below.					

Assessed content of ^{137}Cs in plants is below the maximal allowable level of radioactive contamination of food plants (74 Bq/kg) established by the Ministry of Agriculture of the Republic of Kazakhstan (1994) [6]. Relatively more significant values of the expected specific activities in the plants are observed for ^{90}Sr, exceeding the specified maximal allowable level for a given radionuclide (111 Bq/kg) in the 3rd Zone of radioactive contamination.

Specific activities of $^{239+240}$Pu, ^{241}Am and ^{152}Eu in plants is not specified, but based on the extent of total radiotoxicity of each, we can assume that the allowable level for ^{152}Eu, roughly, corresponds to the allowable specific activity for ^{90}Sr, and for $^{239+240}$Pu and ^{241}Am - an order of magnitude smaller than it [11]. At that the average estimated specific activity of ^{241}Am in plants is within the proposed allowable level, $^{239+240}$Pu – exceeds this in 2nd and 3rd Zones of radioactive contamination, and ^{152}Eu is less than 1% of it.

Quality assessment and forecast for changes in radionuclide contamination of vegetation cover

The vegetative cover of the studied area consists mainly of dry steppes. Content of ^{137}Cs artificial radionuclide in plants does not exceed 10% of the maximal allowable level; concentration of ^{90}Sr is 2 times higher than it [6]. Specific activity of ^{241}Am radionuclide in plants is within the expected allowable level, ^{152}Eu - less than 1% of it. The calculated specific activity of $^{239+240}$Pu is fairly significant and exceeds the estimated allowable level in the plants in the 2nd and 3rd zones of radioactive contamination in the studied area. No abnormal high specific activity of natural radionuclides in the plants was found there.

The level of radionuclide contamination of the vegetation cover primarily depends on the ability of the plants themselves to accumulate radionuclides and availability of the latter, determined by soil characteristics. The introduced "fresh" radionuclides in the first period of stay in the soil may be more available to be accumulated by plants than in later periods, when radionuclides equilibrium has been reached. The intensity of this process depends on the physico-chemical properties of radionuclides. Thus, ^{137}Cs is characterized by clear decrease in entering the plant over time, whereas ^{90}Sr mobility in soil-plant system changes slowly [7]. These facts make it possible to forecast the possible reduction of radionuclide contamination of vegetation in the future. However, at this moment the vegetation in the studied area in terms of its contamination is dangerous and can be considered suitable to conduct appropriate economic activities only if they obey certain rules of radiation safety.

2.6. Assessment of radiological characteristics for products from the studied area

2.6.1. Agricultural products

To assess the radionuclide contents, we first selected transfer factors based on literature data. Transfer factors for assessing radionuclide content in plant products are listed in the paper "Radioecological conditions at the western part of STS territory" published in this issue.

To assess the contamination levels in agricultural products of plant origin, we used data on the average concentration of radionuclides in soils of the studied area and the transfer factors (TC) of radionuclides into various species of crop products, taken from literature data and studies at STS.

During the preparation of the comprehensive survey materials, based on the study of a large array of radioanalytical data, average values of radionuclides specific activities in the soils of the studied area (layer 0-5 cm) were obtained (Table 3). These values were used to calculate the radionuclide content in the steppe motley grasses. Specific activities of radionuclides were calculated in the soil layer 0-20 cm since transfer factors of radionuclides in the garden products were obtained for 0-20 cm soil layer for calculations [4]. Radionuclides activity in the 0-20 cm layer were recalculated in the same way as in the paper "Radioecological conditions at the western part of STS territory" published in this issue.

Since during the areal studies at "Baitemir" field, 3 zones on radiation parameters (Figure 19) were singled out, the average specific activities of the soil (0-20 cm layer) were calculated for each Zone (Table 9).

Table 9.

Average specific activities of radionuclides in the 0-20 cm soil layer for each of the Zones of radionuclide contamination

Zone	Average specific activities of radionuclides, 0-20 cm soil layer, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
I	212.3	972.2	119.5	12.7
II	105.3	110.6	551.3	39.1
III	58.4	129.0	68.3	16.5

The calculated values of radionuclide content in crop products were obtained for the dry weight of plant products, so to convert them into raw mass we used data on the percentage content of dry matter in plants that are listed in the IAEA recommendations [4].

Tables 10-12 show the predicted specific activity of radionuclides in plant products (wet weight) for the case of their production in the studied area and the allowable values for the content of radionuclides in food, according to SanPiN 4.01.071.03 [8]. The allowable levels for $^{239+240}$Pu and ^{241}Am were calculated as in "Radioecological conditions at the western part of STS territory" published in this issue.

Table 10.

Predicted concentrations of radionuclides in crop products (wet weight) in the case of their production in the studied area (calculated based on the average specific activities of radionuclides in the soil of Zone I in the studied area)

Type of products	Predicted and allowable specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Cereals				
Rye	5.3 (70)	54 (40)	$1.3*10^{-3}$ (4.0)	$6.7*10^{-2}$ (4.0)
Wheat	5.4 (70)	55 (40)	$1.3*10^{-3}$ (4.0)	$6.8*10^{-2}$ (4.0)
Barley	8.2 (70)	54 (40)	$1.3*10^{-3}$ (4.0)	$6.7*10^{-2}$ (4.0)
Oat	10.0 (70)	54 (40)	$1.3*10^{-3}$ (4.0)	$6.7*10^{-2}$ (4.0)
Fodder products				
Hay (steppe grasses)	9.0 (74*)	58 (111*)	4.1 (11.1)	$1.1*10^{-1}$ (11.1)
Corn	14 (70)	130 (40)	$7.9*10^{-5}$ (4.0)	1.1 (4.0)

Type of products	**Predicted and allowable specific activity, Bq/kg**			
	^{137}Cs	**^{90}Sr**	**$^{239+240}$Pu**	**^{241}Am**
Leaf vegetables				
Cabbage	1.2 (600)	94 (200)	$1.0*10^{-3}$ (20)	$1.3*10^{-4}$ (20)
Spinach	$8.0*10^{-1}$ (600)	62 (200)	$7.0*10^{-4}$ (20)	$8.7*10^{-5}$ (20)
Leafy celery, lettuce	$6.0*10^{-1}$ (600)	47 (200)	$5.2*10^{-4}$ (20)	$6.6*10^{-5}$ (20)
Bean				
Beans, Peas	2.0 (50)	$5.0*10^{2}$ (60)	$1.8*10^{-3}$ (6.0)	$1.9*10^{-3}$ (6.0)
Fruited vegetables				
Tomatoes, peppers, eggplant	$3.1*10^{-1}$ (600)	35 (200)	$1.6*10^{-4}$ (20)	$2.2*10^{-4}$ (20)
Cucumber	$2.6*10^{-1}$ (600)	29 (200)	$1.3*10^{-4}$ (20)	$1.8*10^{-4}$ (20)
Tuberous root				
Potatoes	1.5 (120)	16 (40)	$6.5*10^{-3}$ (4.0)	$8.7*10^{-4}$ (4.0)
Beet (root crop)	1.2 (600)	81 (200)	$8.4*10^{-3}$ (20)	$6.3*10^{-4}$ (20)
Carrot (root crop)	1.0 (600)	71 (200)	$7.4*10^{-3}$ (20)	$5.5*10^{-4}$ (20)
*Allowable levels for forage vegetation (grass, hay) are established by the Ministry of Agriculture of the Republic of Kazakhstan (^{137}Cs – 74 Bq/kg, ^{90}Sr – 111 Bq/kg)				

Table 11.

Predicted concentrations of radionuclides in crop products (wet weight) in the case of their production in the studied area (calculated based on the specific activities of radionuclides in the soil of Zone II in the studied area)

Type of products	**Predicted and allowable specific activity, Bq/kg**			
	^{137}Cs	**^{90}Sr**	**$^{239+240}$Pu**	**^{241}Am**
Cereals				
Rye	2.6 (70)	6.2 (40)	$5.9*10^{-3}$ (4.0)	$2.1*10^{-1}$ (4.0)
Wheat	2.7 (70)	6.2 (40)	$5.9*10^{-3}$ (4.0)	$2.1*10^{-1}$ (4.0)
Barley	4.1 (70)	6.2 (40)	$5.9*10^{-3}$ (4.0)	$2.1*10^{-1}$ (4.0)
Oat	5.0 (70)	6.2 (40)	$5.9*10^{-3}$ (4.0)	$2.1*10^{-1}$ (4.0)
Fodder products				
Hay (steppe grasses)	4.5 (74*)	6.6 (111*)	19 (11.1)	$3.3*10^{-1}$ (11.1)
Corn	6.8 (70)	15 (40)	$3.7*10^{-4}$ (4.0)	3.5 (4.0)
Leaf vegetables				
Cabbage	$5.9*10^{-1}$ (600)	11 (200)	$4.8*10^{-3}$ (20)	$4.0*10^{-4}$ (20)
Spinach	$4.0*10^{-1}$ (600)	7.1 (200)	$3.2*10^{-3}$ (20)	$2.7*10^{-4}$ (20)
Leafy celery, lettuce	$3.0*10^{-1}$ (600)	5.3 (200)	$2.4*10^{-3}$ (20)	$2.0*10^{-4}$ (20)
Bean				
Beans, Peas	1.0 (50)	57 (60)	$8.2*10^{-3}$ (6.0)	$5.7*10^{-3}$ (6.0)
Fruited vegetables				
Tomatoes, peppers, eggplant	$1.6*10^{-1}$ (600)	4.0 (200)	$7.3*10^{-4}$ (20)	$6.6*10^{-4}$ (20)
Cucumber	$1.3*10^{-1}$ (600)	3.3 (200)	$6.1*10^{-4}$ (20)	$5.5*10^{-4}$ (20)

Type of products	Predicted and allowable specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Tuberous root				
Potatoes	$7.5*10^{-1}$ (120)	1.9 (40)	$3.0*10^{-2}$ (4.0)	$2.7*10^{-3}$ (4.0)
Beet (root crop)	$5.7*10^{-1}$ (600)	9.2 (200)	$3.9*10^{-2}$ (20)	$1.9*10^{-3}$ (20)
Carrot (root crop)	$5.0*10^{-1}$ (600)	8.1 (200)	$3.4*10^{-2}$ (20)	$1.7*10^{-3}$ (20)

Table 12.

Predicted concentrations of radionuclides in crop products (wet weight) in the case of their production in the studied area (calculated based on the specific activities of radionuclides in the soil of Zone III in the studied area)

Type of products	Predicted and allowable specific activity, Bq/kg			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Cereals				
Rye	1.5 (70)	7.2 (40)	$7.3*10^{-4}$ (4.0)	$8.7*10^{-2}$ (4.0)
Wheat	1.5 (70)	7.3 (40)	$7.3*10^{-4}$ (4.0)	$8.8*10^{-2}$ (4.0)
Barley	2.3 (70)	7.2 (40)	$7.3*10^{-4}$ (4.0)	$8.7*10^{-2}$ (4.0)
Oat	2.8 (70)	7.2 (40)	$7.3*10^{-4}$ (4.0)	$8.7*10^{-2}$ (4.0)
Fodder products				
Hay (steppe grasses)	2.5 (74*)	7.7 (111*)	2.3 (11.1)	$1.4*10^{-1}$ (11.1)
Corn	3.8 (70)	18 (40)	$4.5*10^{-5}$ (4.0)	1.5 (4.0)
Leaf vegetables				
Cabbage	$3.3*10^{-1}$ (600)	12 (200)	$6.0*10^{-4}$ (20)	$1.7*10^{-4}$ (20)
Spinach	$2.2*10^{-1}$ (600)	8.3 (200)	$4.0*10^{4}$ (20)	$1.1*10^{-4}$ (20)
Leafy celery, lettuce	$1.6*10^{-1}$ (600)	6.2 (200)	$3.0*10^{-4}$ (20)	$8.5*10^{-5}$ (20)
Bean				
Beans, Peas	$5.6*10^{-1}$ (50)	66 (60)	$1.0*10^{-3}$ (6.0)	$2.4*10^{-3}$ (6.0)
Fruited vegetables				
Tomatoes, peppers, eggplant	$8.6*10^{-2}$ (600)	4.7 (200)	$9.1*10^{-5}$ (20)	$2.8*10^{-4}$ (20)
Cucumber	$7.2*10^{-2}$ (600)	3.9 (200)	$7.5*10^{-5}$ (20)	$2.3*10^{-4}$ (20)
Tuberous root				
Potatoes	$4.2*10^{-1}$ (120)	2.2 (40)	$3.7*10^{-3}$ (4.0)	$1.1*10^{-3}$ (4.0)
Beet (root crop)	$3.2*10^{-1}$ (600)	11 (200)	$4.8*10^{-3}$ (20)	$8.1*10^{-4}$ (20)
Carrot (root crop)	$2.8*10^{-1}$ (600)	9.4 (200)	$4.2*10^{-3}$ (20)	$7.1*10^{-4}$ (20)

The results showed that in the case of growing crops in the studied area, the contents of radionuclides in crop products in most cases would not exceed the allowable concentration of radionuclides in food. However, some plants are expected to have ^{90}Sr exceeding the allowable levels. Thus, at growing corn in the first Zone, specific activity ^{90}Sr will exceed ASA for 3 times. For beans, ^{90}Sr specific activity will exceed or be close to ASA level in all three Zones.

Also the steppe grasses in Zone II are expected to have $^{239+240}$Pu exceeding the projected allowable levels.

2.6.2. Theoretical assessment of the contamination levels in animal products

To assess radionuclide content in animal products, as well as in crop products, the transfer factors are used (ratio of radionuclide concentration in animal products to the daily intake with the diet). Transfer factors for assessing the radionuclide content in animal products are listed in the paper "Radioecological conditions at the western part of STS territory" published in this issue.

2.6.2.1. Assessment of the radionuclide content in animal products

In predicting the concentration of radionuclides in animal products, their concentration in the diet and transfer factors from the diet of the product are taken into account.

Daily intake of radionuclides by animals when they are grazing on the three selected Zones of radionuclide contamination is calculated in the same way as in the "Radioecological conditions at the western part of STS territory" published in this issue. Data on the estimated average daily intake of radionuclides by farm animals are presented in Tables 13-15.

Table 13.

Calculation of possible radionuclide intake by farm animals at grazing in Zone I (based on the calculation of average radionuclide content in soil)

Farm animal	Average weight of a species, kg	Daily intake of pasture forage (dry weight), kg	Intake of radionuclide by one animal, Bq							
			^{137}Cs				^{90}Sr			
			daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake	daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake
Horse	350-400	18	162.4	31.1	379.1	572.6	1041.2	142.5	1736.1	2919.8
Cow	400	16	144.4	27.7	379.1	551.1	925.5	126.7	1736.1	2788.3
Sheep	50-60	2.5	22.6	4.3	47.4	74.3	144.6	19.8	217.0	381.4
Goat	50-60	2	18.0	3.6	47.4	68.9	115.7	15.8	217.0	348.5
Poultry	4-6	0.1*	0.54	-	-	0.54	5.5	-	-	5.5
Intake of transuranic radionuclides										
			$^{239+240}$Pu				^{241}Am			
Horse	350-400	18	73.1	17.5	213.4	304.0	1.9	1.9	22.7	26.5
Cow	400	16	65.0	15.7	213.4	294.0	1.7	1.7	22.7	26.1
Sheep	50-60	2.5	10.2	2.4	26.7	39.3	0.3	0.3	2.8	3.4
Goat	50-60	2	8.1	1.9	26.7	36.7	0.2	0.2	2.8	3.3
Poultry	4-6	0.1*	$1.2*10^{-4}$	-	-	$1.2*10^{-4}$	$7.0*10^{-3}$	-	-	$7.0*10^{-3}$
* Note: Daily rate for poultry is given on a dry weight of wheat (grain)										

Table 14.

Calculation of possible radionuclide intake by farm animals at grazing in Zone II (based on the calculation of average radionuclide content in soil)

Farm animal	Average weight of a species, kg	Daily intake of pasture forage (dry weight), kg	Intake of radionuclide by one animal, Bq							
			^{137}Cs				^{90}Sr			
			daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake	daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake
Horse	350-400	18	15.4	188.0	284.0	118.5	16.2	197.5	332.2	80.6
Cow	400	16	13.7	188.0	273.1	105.3	14.4	197.5	317.2	71.6
Sheep	50-60	2.5	2.1	23.5	36.8	16.5	2.3	24.7	43.4	11.2
Goat	50-60	2	1.7	23.5	34.2	13.2	1.8	24.7	39.7	8.9
Poultry	4-6	0.1*	-	-	0.3	0.6	-	-	0.6	0.3
Intake of transuranic radionuclides										
			$^{239+240}Pu$				^{241}Am			
Horse	350-400	18	337.4	80.8	984.5	1402.7	6.0	5.7	69.8	81.5
Cow	400	16	299.9	71.8	984.5	1356.2	5.3	5.1	69.8	80.2
Sheep	50-60	2.5	46.9	11.2	123.1	181.1	0.8	0.8	8.7	10.3
Goat	50-60	2	37.5	9.0	123.1	169.5	0.7	0.6	8.7	10.0
Poultry	4-6	0.1*	$5.9*10^{-4}$	-	-	$5.9*10^{-4}$	0.02	-	-	0.02
* Note: Daily rate for poultry is given on a dry weight of wheat (grain)										

Table 15.

Calculation of possible radionuclide intake by farm animals at grazing in Zone III (based on the calculation of average values of radionuclide content in soil)

Farm animal	Average weight of a species, kg	Daily intake of pasture forage (dry weight), kg	Intake of radionuclide by one animal, Bq							
			^{137}Cs				^{90}Sr			
			daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake	daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake
Horse	350-400	18	44.7	8.6	104.3	157.5	138.1	18.9	230.4	387.4
Cow	400	16	39.7	7.6	104.3	151.6	122.8	16.8	230.4	369.9
Sheep	50-60	2.5	6.2	1.2	13.0	20.4	19.2	2.6	28.8	50.6
Goat	50-60	2	4.9	0.9	13.0	18.9	15.3	2.1	28.8	46.2
Poultry	4-6	0.1*	0.15	-	-	0.15	0.7	-	-	0.7

Farm animal	Average weight of a species, kg	Daily intake of pasture forage (dry weight), kg	Intake of radionuclide by one animal, Bq							
			^{137}Cs				^{90}Sr			
			daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake	daily intake with food (excluding dust)	daily intake with dust on plants	daily intake with soil	total daily intake
Intake of transuranic radionuclides										
			$^{239+240}$Pu				^{241}Am			
Horse	350-400	18	42.0	10.0	121.9	173.8	2.5	2.4	29.5	34.4
Cow	400	16	37.2	8.9	121.9	168.0	2.2	2.1	29.5	33.9
Sheep	50-60	2.5	5.8	1.4	15.2	22.4	0.4	0.3	3.7	4.4
Goat	50-60	2	4.6	1.1	15.2	21.0	0.3	0.3	3.7	4.2
Poultry	4-6	0.1*	$7.3*10^{-5}$	-	-	$7.3*10^{-5}$	$8.8*10^{-3}$	-	-	$8.8*10^{-3}$
* Note: Daily rate for poultry is given on a dry weight of wheat (grain)										

Table 16 shows the predicted concentrations of radionuclides in animal products in the case of its production in each Zone of radioactive contamination and the allowable concentration of radionuclides in food, according to SanPiN 4.01.071.03 [8]. Allowable levels in animal products for $^{239+240}$Pu and ^{241}Am were calculated as for crop products.

Table 16.

Predicted specific activities of radionuclides in animal products at grazing in Zones I, II and III (based on the calculation of average radionuclides content in soil)

Product type	Predicted concentration, Bq/kg (allowable concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Zone I				
Horse				
mare's milk (koumiss)	13.2(100)	8.20 (25)	$3.0*10^{-3}$ (2.5)	$1.11*10^{-5}$ (2.5)
meat (horseflesh)	29.2 (160)	23.4 (50)	$1.82*10^{-2}$ (5.0)	$1.32*10^{-2}$ (5.0)
Black cattle				
Milk	12.7 (100)	7.81 (25)	$2.94*10^{-3}$ (2.5)	$1.09*10^{-5}$ (2.5)
meat (beef)	28.1 (160)	22.3(50)	$1.76*10^{-2}$ (5.0)	$1.30*10^{-2}$ (5.0)
Sheep				
sheep milk	5.72 (100)	21.4 (25)	$3.93*10^{-3}$ (2.5)	-
meat (mutton)	17.1(160)	$4.20*10^{-2}$ (50)	$2.08*10^{-3}$ (5.0)	$3.70*10^{-4}$ (5.0)
Goat				
Milk	8.96 (100)	9.76 (25)	-*	$2.25*10^{-5}$ (2.5)
Meat	33.1 (160)	1.05 (50)	-	-
Poultry				
Meat	6.45 (180)	$4.39*10^{-1}$ (80)	-	-
Eggs	$2.42*10^{-1}$ (80)	4.83 (50)	-	-

Product type	Predicted concentration, Bq/kg (allowable concentration, Bq/kg)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
Zone II				
Horse				
mare's milk (koumiss)	6.53(100)	$9.3*10^{-1}$(25)	$1.40*10^{-2}$ (2.5)	$3.42*10^{-5}$ (2.5)
meat (horseflesh)	14.5 (160)	2.66 (50)	$8.42*10^{-2}$ (5.0)	$4.08*10^{-2}$ (5.0)
Black cattle				
Milk	6.29 (100)	$8.88*10^{-1}$ (25)	$1.36*10^{-2}$ (2.5)	$3.37*10^{-5}$ (2.5)
meat (beef)	13.9 (160)	2.54(50)	$8.14*10^{-2}$ (5.0)	$4.01*10^{-2}$ (5.0)
Sheep				
sheep milk	2.84 (100)	2.43 (25)	$1.81*10^{-2}$ (2.5)	-
meat (mutton)	8.47(160)	$4.77*10^{-3}$(50)	$9.60*10^{-3}$ (5.0)	$1.14*10^{-3}$ (5.0)
Goat				
Milk	4.44 (100)	1.11 (25)	-*	$6.92*10^{-5}$ (2.5)
Meat	16.4 (160)	$1.19*10^{-1}$(50)	-	-
Poultry				
Meat	3.20 (180)	$4.99*10^{-2}$ (80)	-	-
Eggs	$1.20*10^{-1}$ (80)	$5.49*10^{-1}$ (50)	-	-
Zone III				
Horse				
mare's milk (koumiss)	3.6(100)	1.08 (25)	$1.74*10^{-3}$ (2.5)	$1.45*10^{-5}$ (2.5)
meat (horseflesh)	8.03 (160)	3.1 (50)	$1.04*10^{-2}$ (5.0)	$1.72*10^{-2}$ (5.0)
Black cattle				
Milk	3.49 (100)	1.04 (25)	$1.68*10^{-3}$ (2.5)	$1.42*10^{-5}$ (2.5)
meat (beef)	7.73 (160)	2.96(50)	$1.01*10^{-2}$ (5.0)	$1.69*10^{-2}$ (5.0)
Sheep				
sheep milk	1.57 (100)	2.83 (25)	$2.24*10^{-3}$ (2.5)	-
meat (mutton)	4.70(160)	$5.57*10^{-3}$(50)	$1.19*10^{-3}$ (5.0)	$4.81*10^{-4}$ (5.0)
Goat				
Milk	2.46 (100)	1.29 (25)	-*	$2.92*10^{-5}$ (2.5)
Meat	9.10 (160)	$1.39*10^{-1}$(50)	-	-
Poultry				
Meat	1.77 (180)	$5.83*10^{-2}$ (80)	-	-
Eggs	$6.65*10^{-2}$ (80)	$6.41*10^{-1}$ (50)	-	-
* Note: - there is no forecast values due to lack of Tc				

The studies have shown that in the animal origin agricultural products obtained in the studied area of the STS territory the concentration of radionuclides does not exceed the established norms, although that the calculations are based on the most conservative values of the parameters used. Accordingly, consumption of these products in food will not pose a threat to public health. Only some arable crops are expected to have specific activity of ^{90}Sr exceeding the allowable levels. Thus, at growing corn in the first Zone the specific activity of ^{90}Sr will 3 times exceed the ASA. For beans, ^{90}Sr specific activity will exceed or remain at

ASA level in all three Zones. Also, the steppe grasses of Zone II are expected to have $^{239+240}Pu$ contents exceeding the projected allowable levels.

2.7. State of water bodies

To study possible contamination of the aquatic environment in the field area, we took 7 samples of groundwater from hydrogeological wells (Figure 26).

Results of the laboratory tests are presented in Table 17 below.

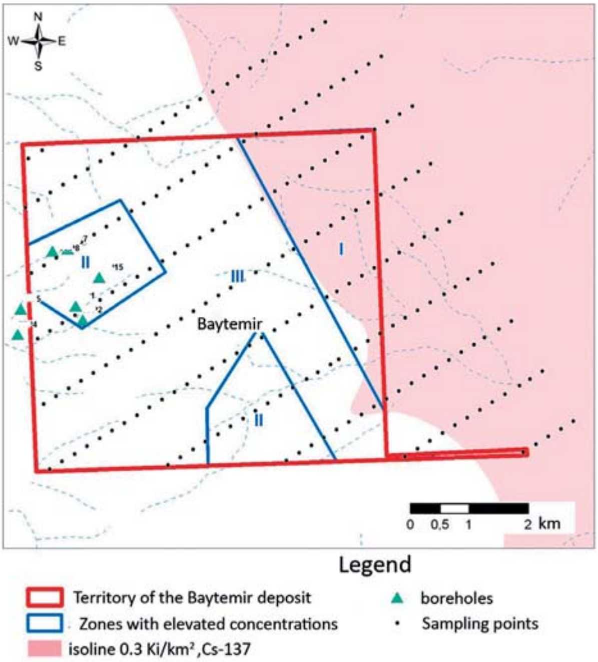


Figure 26. "Baitemir" field. Arrangement of water sampling points

Table 17.

Analysis of water samples taken at "Baitemir" field

Sampling point	Sampling date	^{241}Am, Bq/kg	^{137}Cs, Bq/kg	^{90}Sr, Bq/kg	$^{239+240}Pu$, Bq/kg	^{3}H, kBq/kg
well GGR1	02.11.2010	<0.5	<0.5	<0.01	<0.0023	<0.017
well GGR2	02.11.2010	<0.5	<0.2		<0.0028	<0.017
well GGR4	02.11.2010	<0.4	<0.5		<0.0023	<0.017
well GGR5	02.11.2010	<0.5	<0.2	<0.01		<0.017
well GGR7	02.11.2010	<0.4	<0.4		<0.0032	<0.017
well GGR8	02.11.2010	<0.3	0.9	<0.01	<0.0025	<0.019
well GGR15	02.11.2010	<0.5	<0.4		<0.0042	<0.019

According to the laboratory studies, the concentration of artificial radionuclides in the samples does not exceed MDA of used equipment. These values do not pose radiation hazard and are well below the intervention levels for the public when intake of radionuclides with food and water set by the NRB-99 (Annex P-2).

In considering the likelihood of inflow of radioactively contaminated waters from underground nuclear explosions into the groundwater of the field, such basic factors were used as features of the geological structure of STS and data on testing the water wells for content of artificial radionuclides. It should be noted that the STS is characterized by number of regional faults of northeast outstretch and large faults of meridional and northeast outstretch (Figure 27).

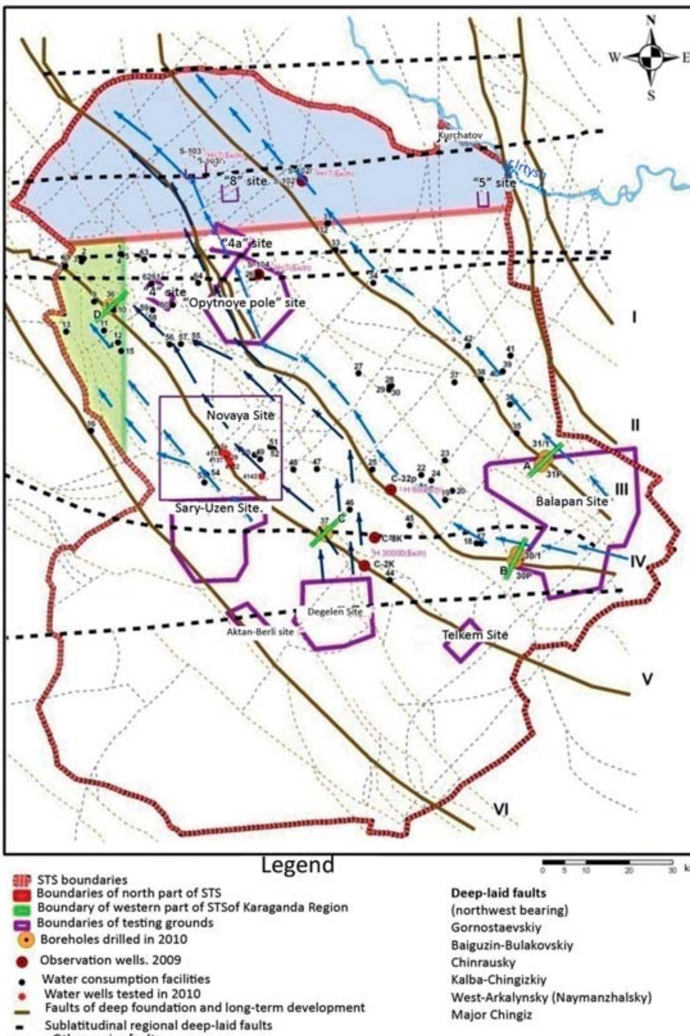


Figure 27. Territory of STS. Possible main proliferation directions for contaminated groundwater

These studies of the main possible pathways for contaminated groundwater migration from the nuclear explosion venues at the sites "Degelen", "Balapan", "Sary-Uzen" into the water of the field made us believe that, considering the expected levels of radioactive contamination of groundwater at the surface of the area, any business activities without any restrictions can be allowed there.

Ecological and geological aspects of "Baitemir" filed development

Hydrogeological conditions in the area and "Baitemir" field considering its open cast mining are very simple. Lack of strong water-bearing formations with large natural reserves and resources of surface waters allows attributing the field to the category of moderately-watered and operation of it, apparently, will not cause any great difficulties. An industrial development of the field may cause ecological complications due to the proximity of "Sary-Uzen" underground nuclear test site.

Currently the territory of "Baitemir" field has no widespread contamination of groundwater with radionuclides. This does not mean that the situation is safe for business in this area. Migration of any substance with water, formation and proliferation of groundwater, depending on many factors, occur during a long time. Very low water conducting properties of the rocks embedding the contamination sources ("warfare" borehole), alternation of water-bearing fracture zones and faults of solid Paleozoic rocks, substantial depth of explosion hypocenters, poor infiltration recharge cause very slow water exchange in the field. Therefore, in present natural conditions, the impact from underground hydrosphere contamination in adjacent to the contamination sources areas, in one way or another, may appear in tens, hundreds or even thousands of years. This is true for the natural environment and has been verified by geological studies.

It is quite another thing when geological environment begins to be subjected to intense anthropogenic influence which is the industrial development of "Baitemir" field. Construction of a pit will result in formation of a depression cone that will cover the area where "warfare" boreholes are. At that, the biases of piezometric surface crack and fracture-vein waters will increase substantially causing an adequate strengthening of migration and proliferation of groundwater towards the pit. These are basic changes in the underground hydrosphere during servicing the pit, and it is not yet possible to predict at which stage of the minefield development the pit water would get contaminated with radionuclides and whether it happens at all. In such cases, operational monitoring and prediction of quality are possible only based on the monitoring of groundwater, arrangement of which should take into account the likely number of hydrodynamic characteristics of the formation of water inflow into the pit.

It should be borne in mind that in this area the main radioactive contaminant of groundwater is tritium. The main feature of this radionuclide’s migration property is that it is a part of the water and not sorbed by rocks. In this connection, enlargement of the depression cone may cause inflow of tritium contaminated groundwater into the pit in a relatively short time.

2.8. Air basin

No specific studies of the field air basin have been carried out before. During the survey 1 sample was taken (of no less than 400 m^3) in the field, which was analyzed by radiochemical and gamma spectrometric methods in accordance with techniques [9, 10] for content of natural and artificial radionuclides. The results of laboratory studies are presented in Table 18.

Table 18.

Laboratory radiochemical and gamma spectrometric measurements of natural and artificial radionuclides in the samples of air aerosols (Bq/m^3)

Sampling point	$^{239+240}$Pu	^{90}Sr	^{241}Am	^{137}Cs	^{226}Ra	^{232}Th	^{40}K
т. 138	$<1.2\cdot10^{-4}$	$6.2\cdot10^{-4}\pm 1.8\cdot10^{-4}$	$<1\cdot10^{-4}$	$<2\cdot10^{-4}$	$2\cdot10^{-3}\pm 3\cdot10^{-4}$	$<2\cdot10^{-3}$	$8\cdot10^{-3}\pm 8\cdot10^{-4}$
AVA_{pers}, Bq/m^3	$5.3\cdot10^{-1}$	$3.3\cdot10^{2}$	2.5	$2.1\cdot10^{-1}$	$1.7\cdot10^{3}$	0.19	$3.8\cdot10^{3}$
AVA_{pop}, Bq/m^3	$2.5\cdot10^{-3}$	2.7	$3.0\cdot10^{-2}$	$2.9\cdot10^{-3}$	27	$4.9\cdot10^{-3}$	31

The results revealed that concentration of natural and artificial radionuclides does not exceed the allowable values of volumetric activity for both category "personnel" (AVA_{pers}) and for the category "population" (AVA_{pop}) [11].

The main potential sources of air pollution in the field may include: areas with contamination caused by atmospheric fallouts from tests conducted at "Experimental field" site, abnormal radiological situation at the sites "Sary Uzen", "Degelen", "Balapan". However, given the spatial arrangement of the territory, the most likely source of inflow of artificial radionuclides into the air will be migration of contaminated soil particles from radioactive fallout trace of the first thermonuclear test device (12.08.1953). Therefore, there is a great likelihood of getting the artificial radionuclides from the possible contaminated areas into the surface atmosphere during stripping operations. In this connection, it is recommended to carry out continuous monitoring of air pollution.

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

The results from the study [part 2.3] have determined that in "Baitemir" field 3 Zones were singled out for which we calculated mean values of specific activities of artificial radionuclides in surface soil layer. Specific activities of artificial radionuclides in Zones I, II and III are shown in Table 3.

The volumetric activity of radionuclides in the air of "Baitemir" field was defined as follows:

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

where: C_{airi} – volumetric activity of the *i* radionuclide in air (Bq/m^3);

C_i – specific activity of the *i* radionuclide in the surface layer of soil, Bq/kg;

ρ_{sus} – annual average dustiness of air, kg/m^3.

Average annual natural dustiness of the air, according to [12], outdoors and indoors is $1\cdot10^{-7}$ kg/m^3. The report published by the European Commission [13] say that during natural or human caused dusting the air dustiness may increase up to 10-100 times, that is, up to $1\cdot10^{-6}$– $1\cdot10^{-5}$ kg/m^3. Therefore, when assessing contents of radionuclides in the air, we examine average annual air dustiness ($1\cdot10^{-6}$ kg/m^3).

Artificial radionuclides content in the air of "Baitemir" field was assessed based on the average specific activity of artificial radionuclides in Zones I, II and III.

The calculated volumetric activities of artificial radionuclides in the air of the studied area, taking into account the average annual air dustiness are given in the following table (Table 19).

Table 19.

Volumetric activity of artificial radionuclides in the air of the western territory and areas with high content of artificial radionuclides

Average annual air dustiness (ρ_{sus}), kg/m^3	Volumetric activity of radionuclides in air at average values of specific activity in the soil, Bq/m^3			
	^{137}Cs	^{90}Sr	$^{238+239+240}$Pu	^{241}Am
Zone I				
10^{-6}	$2.1\cdot10^{-4}$	$9.7\cdot10^{-4}$	$1.2\cdot10^{-4}$	$1.3\cdot10^{-5}$
Zone II				
10^{-6}	$1.1\cdot10^{-4}$	$1.1\cdot10^{-4}$	$5.7\cdot10^{-4}$	$3.9\cdot10^{-5}$
Zone III				
10^{-6}	$5.8\cdot10^{-5}$	$1.3\cdot10^{-4}$	$7.5\cdot10^{-5}$	$1.7\cdot10^{-5}$
AVA$_{pop}$, Bq/m^3	$2.7\cdot10^{1}$	2.7	$2.5\cdot10^{-3}$*	$2.9\cdot10^{-3}$
Note: * - allowable volumetric activity of $^{238+239+240}$Pu is taken as $2.5\cdot10^{-3}$ for ^{239}Pu				

The obtained volumetric activities of artificial radionuclides in the air of "Baitemir" field at average specific activity in the surface layer of soil in Zones I, II and III do not exceed allowable values according to NRB-99 at average annual dustiness equal to $1\cdot10^{-6}$ kg/m^3. At higher dust load, the volumetric activity of $^{238+239+240}$Pu will exceed the allowable values for the population in Zone II, because its content in the surface soil layer is 572 Bq/kg.

Thus, the theoretical estimates of the radionuclide contents in the air of "Baitemir" field showed that the volumetric activity of radionuclides at mean values of specific activity and values of annual average dustiness equal to $1\cdot10^{-6}$ kg/m^3 do not exceed the allowable values for the population.

3. ASSESSMENT OF DOSE LOADS TO POPULATION AND PERSONNEL WHEN RESIDING AND CARRYING OUT ACTIVITIES IN THE STUDIED AREA

In this paper when estimating the expected annual effective doses on the population we do not take into account the doses from natural radiation, 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 surface soil layer.

To make things simple in assessing the dose loads, the following assumptions were made:

- reduction in rates of external doses when covering the soil with snow (winter period) and use of personal protective equipment were not taken into account;
- changes in air dustiness, depending on the season were not taken into account;
- ignored the increase in height (1.5-2 meters) above the ground and shielding with vehicles (for farmers) or body of horse (to shepherd) during residing and carrying out activities in the investigated territory of the STS;
- ignored the internal doses from radionuclides from consumption of water by staff and local population from the local sources as the specific activity levels of artificial radionuclides in water are below the detection limits of the equipment used: ^{137}Cs< 0.4 Bq/kg, ^{90}Sr< 0.01 Bq/kg, $^{239+240}$Pu< 0.003. ^{3}H< 17 Bq/kg, that is 1-3 orders of magnitude below the intervention levels for drinking water, according to NRB-99;
- ignored the internal dose from imported food products.

It is assumed that the contamination is distributed evenly over the site area, whereas distribution in the soil horizon is exponentially.

According to NRB-99, the dose coefficients used to estimate doses at intakes of radionuclides with air are not divided into age groups.

Dose coefficients of ^{238}Pu are comparable with $^{239+240}$Pu; when assessing the doses we accounted isotopes of $^{238+239+240}$Pu.

3.1. Technique for determination of dose loads

Basic techniques are presented in the monograph "Semipalatinsk Test Site: Radiological Situation of the Northern Lands" [1].

3.2. Initial data

3.2.1. Selection of parameter values used in calculating the dose loads

The results from the studies determined that "Baitemir" field in the surface layer of soil contains the following major dose-forming artificial radionuclides: ^{90}Sr, ^{137}Cs, $^{238+239+240}$Pu, ^{241}Am. The results of the experimentally determined average contents of artificial radionuclides in the surface (5 cm) soil layer and for areas with higher contents of artificial radionuclides in the studied area of STS are presented in Table 20.

Table 20.

Specific and areal activities of artificial radionuclides in surface soil of "Baitemir" field in the STS

Zone I			
Average values of specific activity, Bq/kg			
^{137}Cs	**^{90}Sr**	**$^{238+239+240}$Pu**	**^{241}Am**
212	972	121	12.7
Areal activity of radionuclides at average specific activity, Bq/m^2			
^{137}Cs	**^{90}Sr**	**$^{238+239+240}$Pu**	**^{241}Am**
13,800	63,200	7,850	826

Zone II			
Average values of specific activity, Bq/kg			
^{137}Cs	**^{90}Sr**	**$^{238+239+240}$Pu**	**^{241}Am**
105	111	572	39
Areal activity of radionuclides at average specific activity, Bq/m^2			
^{137}Cs	**^{90}Sr**	**$^{238+239+240}$Pu**	**^{241}Am**
6,840	7,190	37,200	2540
Zone III			
Average values of specific activity, Bq/kg			
^{137}Cs	**^{90}Sr**	**$^{238+239+240}$Pu**	**^{241}Am**
58	129	75	16.5
Areal activity of radionuclides at average specific activity, Bq/m^2			
^{137}Cs	**^{90}Sr**	**$^{238+239+240}$Pu**	**^{241}Am**
3,800	8,380	4,860	1,070

The parameter values used in the assessment of dose loads from considered pathways of exposure due to artificial radionuclides are given in Table 21.

Table 21.

Values of the coefficients used in the assessment of dose loads

Coefficients	Coefficient values			
	^{137}Cs	^{90}Sr	$^{238+239+240}$Pu	^{241}Am
B_{sg}, mGy ·m^2/h·kBq	$2.5 \cdot 10^{-6}$	$1.0 \cdot 10^{-9}$	$1.3 \cdot 10^{-9}$	$9.7 \cdot 10^{-8}$
$e_{inhpop,}$ Sv/Bq	$4.6 \cdot 10^{-9}$	$5.0 \cdot 10^{-8}$	$5.0 \cdot 10^{-5}$	$4.20 \cdot 10^{-5}$
e_{dt} (adult), Sv/Bq	$1.3 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$	$2.5 \cdot 10^{-7}$	$2.0 \cdot 10^{-7}$
e_{dt} (child 7-12 years old), Sv/Bq	$1.0 \cdot 10^{-8}$	$6.0 \cdot 10^{-8}$	$2.7 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$
e_{dt} (infant 1-2 years old), Sv/Bq	$1.2 \cdot 10^{-8}$	$7.3 \cdot 10^{-8}$	$4.2 \cdot 10^{-7}$	$3.7 \cdot 10^{-7}$

3.2.2. Selection of values for the annual food consumption parameters and expected values of the radionuclides specific activities in products

To assess the internal dose from food produced in contaminated areas, it is necessary to know the volume of annual consumption of food.

Consumption standards of staple foods for different social groups, which represent the minimal food needed for human life, are listed in the *Law of the Republic of Kazakhstan dated November 16, 1999 № 474-I "On Living Wage"* [14].

These standards are averaged values for people of Kazakhstan, and may significantly differ for different groups and segments of population.

Therefore, in order to assess the radiation exposure from the consumption of food produced within the studied area, a public inquiry was carried out, allowing specifying the parameters of the food basket. The public were asked to answer the following questions: basic characteristics of the household; whether there is a garden; types of economic activities carried out in the STS; annual consumption of food products made. The survey found that the amount of and food patterns for people living in the STS are different from the minimal standards of consumption of basic foodstuffs, towards the increasing the consumption of meat and dairy products. Based on the survey and living conditions of the population, changes were made in the rates of consumption of staple foods that can be produced and consumed by the population in the studied area.

Predicted radionuclides specific activities in animal and crop products are calculated using the transfer factors of radionuclides presented in the IAEA documents [4]. Based on the selected transfer factors into crop and livestock products there have been calculated the expected specific activities of radionuclides, which are then used to assess the dose loads received from artificial radionuclides through food chains.

The expected specific activities of radionuclides in crop and livestock goods being produced in the studied area are shown in Tables 22-23.

Table 22.

Expected specific activities of radionuclides in animal products at average contents of artificial radionuclides in surface soil layer for Zones I, II and III

Type of product	Specific activity of radionuclides, Bq/kg											
	^{137}Cs			^{90}Sr			$^{239+240}Pu$			^{241}Am		
	I	II	III	I	II	III	I	II	III	I	II	III
Black cattle												
milk	12.7	6.3	3.5	7.8	0.9	1.0	$2.9\cdot10^{-3}$	$1.3\cdot10^{-2}$	$1.7\cdot10^{-3}$	$1.1\cdot10^{-5}$	$3.4\cdot10^{-5}$	$1.4\cdot10^{-5}$
meat (beef)	28.1	13.9	7.7	22.3	2.5	3.0	$1.7\cdot10^{-2}$	$8.1\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.3\cdot10^{-2}$	$4.0\cdot10^{-2}$	$1.7\cdot10^{-2}$
20% fat sour cream	2.5	1.3	$6.9\cdot10^{-1}$	1.6	$1.8\cdot10^{-1}$	$2.1\cdot10^{-1}$	$5.9\cdot10^{-4}$	$2.7\cdot10^{-3}$	$3.4\cdot10^{-4}$	$2.2\cdot10^{-6}$	$6.7\cdot10^{-6}$	$2.8\cdot10^{-6}$
semifat curd	$5.1\cdot10^{-1}$	$2.5\cdot10^{-1}$	$1.4\cdot10^{-1}$	$3.1\cdot10^{-1}$	$3.6\cdot10^{-2}$	$4.1\cdot10^{-2}$	$1.2\cdot10^{-4}$	$5.4\cdot10^{-4}$	$6.7\cdot10^{-5}$	$4.4\cdot10^{-7}$	$1.4\cdot10^{-6}$	$5.7\cdot10^{-7}$
Horse meat												
meat	29.2	14.5	8.0	23.4	2.7	3.1	$1.8\cdot10^{-2}$	$8.4\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.3\cdot10^{-2}$	$4.1\cdot10^{-2}$	$1.7\cdot10^{-2}$
koumiss (mare's milk)	13.1	6.5	3.6	8.2	$9.3\cdot10^{-1}$	1.1	$3.0\cdot10^{-3}$	$1.4\cdot10^{-2}$	$1.7\cdot10^{-3}$	$1.1\cdot10^{-5}$	$3.4\cdot10^{-5}$	$1.5\cdot10^{-5}$
Sheep												
meat (mutton)	17.1	8.5	4.7	$4.2\cdot10^{-2}$	$4.8\cdot10^{-3}$	$5.6\cdot10^{-3}$	$2.1\cdot10^{-3}$	$9.6\cdot10^{-3}$	$1.1\cdot10^{-3}$	$3.7\cdot10^{-4}$	$1.1\cdot10^{-3}$	$4.8\cdot10^{-4}$
Poultry												
meat	6.4	3.2	1.7	$4.4\cdot10^{-1}$	$5.0\cdot10^{-2}$	$5.8\cdot10^{-2}$	-*	-	-	-	-	-
eggs	$2.4\cdot10^{-1}$	$1.2\cdot10^{-1}$	$6.7\cdot10^{-2}$	4.8	$5.5\cdot10^{-1}$	$6.4\cdot10^{-1}$	-	-	-	-	-	-
Note: * "-" no forecast values due to lack of T_c												

Table 23.

Expected content of radionuclides in crop goods produced in the studied area at average specific activities in the surface soil layer for Zones I, II and III

Type of product	Specific activity of radionuclides, Bq/kg											
	^{137}Cs			^{90}Sr			$^{239+240}Pu$			^{241}Am		
	I	II	III	I	II	III	I	II	III	I	II	III
Cereals												
Rye	5.3	2.6	1.5	54.3	6.2	7.2	$1.3\cdot10$-^{3}	$5.9\cdot10^{-3}$	$7.3\cdot10^{-4}$	$6.7\cdot10^{-2}$	$2.1\cdot10^{-1}$	$8.7\cdot10^{-2}$
Wheat	5.4	2.7	1.5	54.9	6.2	7.3	$1.3\cdot10$-^{3}	$5.9\cdot10^{-3}$	$7.3\cdot10^{-4}$	$6.8\cdot10^{-2}$	$2.1\cdot10^{-1}$	$8.8\cdot10^{-2}$
Oat	10.1	5.0	2.8	54.3	6.2	7.2	$1.3\cdot10$-^{3}	$5.9\cdot10^{-3}$	$7.3\cdot10^{-4}$	$6.7\cdot10^{-2}$	$2.1\cdot10^{-1}$	$8.7\cdot10^{-2}$
Leaf vegetable												
Cabbage	1.2	$5.9\cdot10^{-1}$	$3.3\cdot10^{-1}$	93.5	10.6	12.4	$1.0\cdot10^{-3}$	$4.8\cdot10^{-3}$	$6.0\cdot10^{-4}$	$1.3\cdot10^{-4}$	$4.0\cdot10^{-4}$	$1.7\cdot10^{-4}$
Legumes												
Bean, pea	2.0	1.0	$5.6\cdot10^{-1}$	497	56.5	66	$1.8\cdot10^{-3}$	$8.2\cdot10^{-3}$	$1.0\cdot10^{-3}$	$1.9\cdot10^{-3}$	$5.7\cdot10^{-3}$	$2.4\cdot10^{-3}$
Fruited vegetables												
Tomato	$3.1\cdot10^{-1}$	$1.6\cdot10^{-1}$	$8.6\cdot10^{-2}$	35.1	4.0	4.7	$1.6\cdot10^{-4}$	$7.3\cdot10^{-4}$	$9.1\cdot10^{-5}$	$2.2\cdot10^{-4}$	$6.6\cdot10^{-4}$	$2.8\cdot10^{-3}$
Cucumber	$2.6\cdot10^{-1}$	$1.3\cdot10^{-1}$	$7.2\cdot10^{-2}$	29.2	3.3	3.9	$1.3\cdot10^{-4}$	$6.1\cdot10^{-4}$	$7.5\cdot10^{-5}$	$1.8\cdot10^{-4}$	$5.5\cdot10^{-4}$	$2.3\cdot10^{-4}$
Tuberous root												
Potato	1.5	$7.5\cdot10^{-1}$	$4.2\cdot10^{-1}$	16.4	1.9	2.17	$6.5\cdot10^{-3}$	$3.0\cdot10^{-2}$	$3.7\cdot10^{-3}$	$8.7\cdot10^{-4}$	$2.7\cdot10^{-3}$	$1.1\cdot10^{-3}$
Beet (root crop)	1.2	$5.7\cdot10^{-1}$	$3.2\cdot10^{-1}$	81.1	9.2	10.8	$8.4\cdot10^{-3}$	$3.9\cdot10^{-2}$	$4.8\cdot10^{-3}$	$6.3\cdot10^{-4}$	$1.9\cdot10^{-3}$	$8.1\cdot10^{-4}$
Carrot (root crop)	1.0	$5.0\cdot10^{-1}$	$2.8\cdot10^{-1}$	71	8.1	9.4	$7.4\cdot10^{-3}$	$3.4\cdot10^{-2}$	$4.2\cdot10^{-3}$	$5.5\cdot10^{-4}$	$1.6\cdot10^{-3}$	$7.1\cdot10^{-4}$
Note: * "-" no forecast values due to lack of T_c												

3.3. Behaviour scenarios for population and personnel at "Baitemir" minefield

In assessing the dose loads to the population residing in "Baitemir" field, an agricultural scenario of behaviour was examined.

3.3.1. Agricultural scenario

This scenario is conventionally called "subsistence farming" and considers the living conditions of people in the studied area. The scenario is described in the article "Radioecological conditions at the western part of STS territory" published in this issue. From the experience of our calculations, the values of doses for women and children are below the values of doses for a farmer and shepherd; therefore dose loads in the agricultural behaviour scenario to population were assessed for farmer and shepherd.

In assessing the dose loads to staff engaged in various activities in "Baitemir" field, two scenarios were examined: research scenario, which consists of exploration operations and industrial, including construction, mining ores and rare metals and their processing.

3.3.2. Research scenario (geologic exploration)

This scenario examines the behaviour of personnel during geological surveys in the studied area. The geological survey lasts 8 months in the field season. The time that is spent outdoors by a geologist, while working and disturbing the upper soil layer (from the manual or mechanical digging) is 8 hours per day. The air dustiness during the works is taken as 10^{-5} kg/m^3. Office works to process the data, cooking and eating in the open air last 6 hours per day. The geologists reside within the survey area in caravans or tents. The air dustiness is accepted as 10^{-7} kg/m^3. We did not consider the shielding with walls of caravans in assessing the external doses.

Summary data on the time spent outdoors and indoors are given in Table 24.

Table 24.

Time T, spent under contamination conditions according to research scenario of behaviour

Factor	Measuring unit	Geologic exploration
Time spent outdoors at geological works	hour/year	1,920
Time spent outdoors at office work and leisure	hour/year	1,440

3.3.3. Industrial scenario

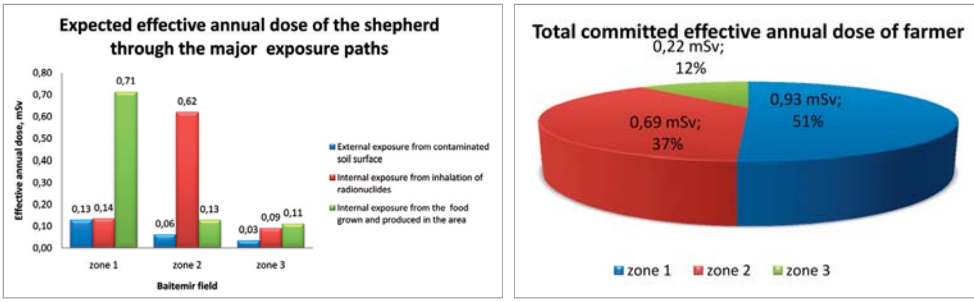
The scenario examines the dose loads gained by the workers during the construction of structures, mining ore and rare metals and doses to employees (workers) of industrial sites (factories) in the studied area. The doses are considered for adults who work in shifts and spend in the studied area 4,380 hours per year. The workers spend 8 hours a day in the open air or in the production room of a factory. Period of time when the worker is directly involved in work, disturbing the top soil is 1,456 hours. The air dustiness during the works is taken as 10^{-5} kg/m^3 [4]. No protective measures (gloves, vehicle shielding and buildings) are considered. The workers and administrative staff members reside in a residential area, located within the studied area. Time spent in caravans is 2,647 hours per year. The air dustiness in a residential area is taken as 10^{-7} kg/m^3. We did not consider shielding with walls of caravans in assessing the external doses. The distance from the residential town to the factory is 5 km. The time spent on the road from the residential zone to an industrial area and lunch is 1.5 hours per day. When transporting the workers on a country (ground) road shielding factor with vehicles is taken into account. Workers consume imported food and water.

In assessing the external dose to the administrative staff, the shielding with walls of industrial buildings is taken into account. The air dustiness is taken as 10^{-6} kg/m^3.

3.4. Findings of the assessment of dose loads to public and workers residing and carrying out activities in the studied area

Assessment of dose loads to population and personnel during the residence and activities in the studied area was based on methods for dose calculation, input data and behaviour scenario of the population in the studied area [1]. The input data are shown in Tables 20-21.

The histogram (Figure 28) shows the distribution of the expected annual effective dose of a farmer from various exposure pathways for each of the designated Zones.



a) b)

Figure 28. Expected annual effective dose for the agricultural behaviour scenario of the farmer in "Baitemir" field in Zones I, II, III:
a) through major exposure pathways, and b) the total on all exposure pathways

The figure shows that the main contribution to the dose loads to farmers in Zone I is made by internal dose received from food grown and produced in the territory where major contribution is made by the radionuclide ^{90}Sr (^{90}Sr specific activity in Zone I is 972 Bq/kg). In Zones II and III the major contribution to the dose load is made by internal dose from inhalation of the radionuclide $^{238+239+240}$Pu (specific activity of $^{238+239+240}$Pu is 572 and 75 Bq/kg, respectively).

The most dangerous area in "Baitemir" field is Zone I, where expected annual effective dose for the farmer will be 0.93 mSv. Figure 29 shows contribution of the considered artificial radionuclides into expected annual effective dose for the farmer from a variety of exposure pathways for each of the designated Zones.

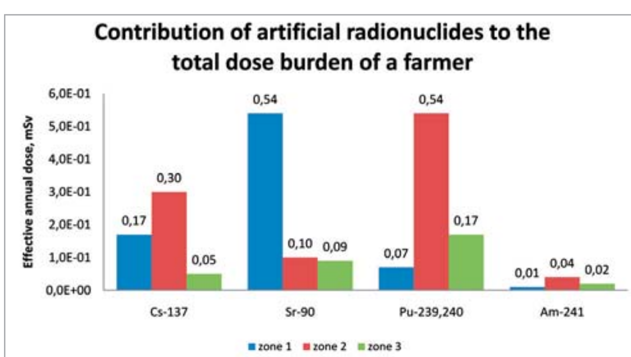
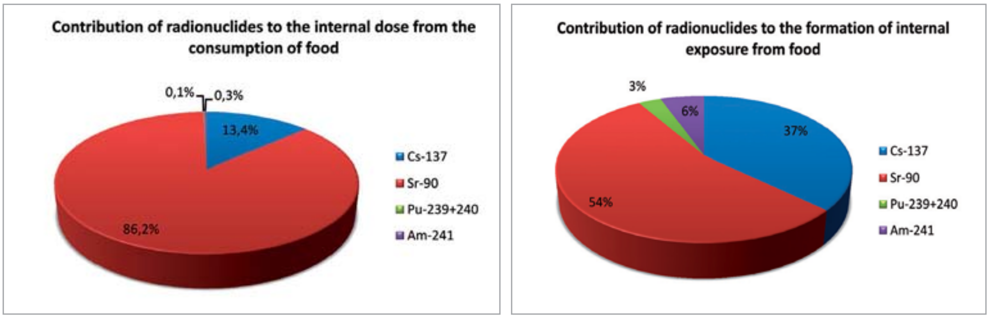


Figure 29. Contribution of artificial radionuclides into expected annual effective dose of a farmer through major exposure pathways in Zones I, II, III of "Baitemir" field

The main contribution to dose loads to farmers at average specific activities of radionuclides in surface soil layer in Zone I and III is made by internal dose from food grown and produced in the studied area (~ 77% and 51%); in Zone II it is internal exposure from inhalation of contaminated dust particles (73%). External dose from the contaminated surface soil is about 11% of the total annual effective dose in Zone I, 8% in Zone II and 14% in Zone III. The main contribution to the dose for the farmer from external exposure is made by ^{137}Cs. Contribution to internal dose from inhalation of radionuclides is made by $^{238+239+240}Pu$ (94%).

The major dose-forming radionuclide in food in the studied area is ^{90}Sr (Figure 30).



a) b)

Figure 30. Contribution of artificial radionuclides in the formation of internal doses from food being grown and produced in Zone I (a) and Zone II (b)

Contribution to the effective annual dose when incorporated with food for an adult is 73% in crop and 27% in livestock products. The main contribution to the expected annual dose being received from livestock products at average values of the specific activities of radionuclides in surface soil layer is by dairy products 56% for adults.

The results of the expected annual effective dose for the agricultural scenario for the shepherd at average values of specific activities of artificial radionuclides in surface soil of Zone I, Zone II and Zone III, are shown in Figure 31.

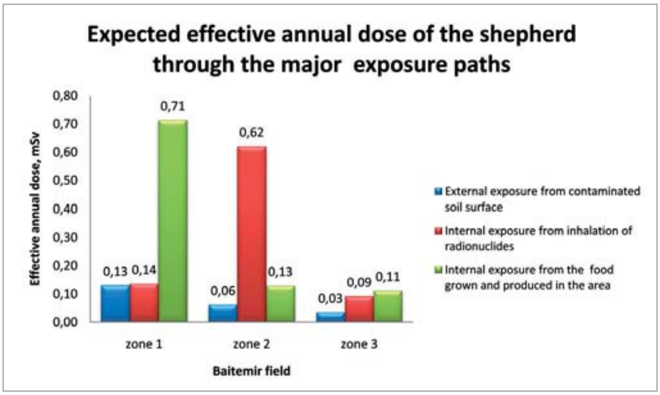
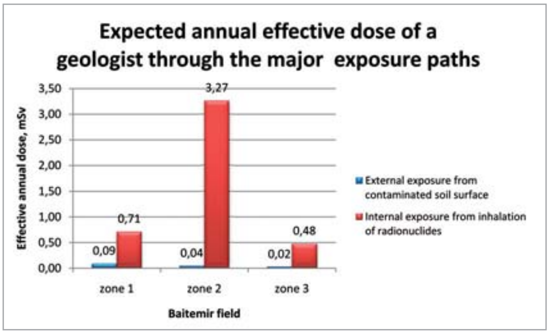


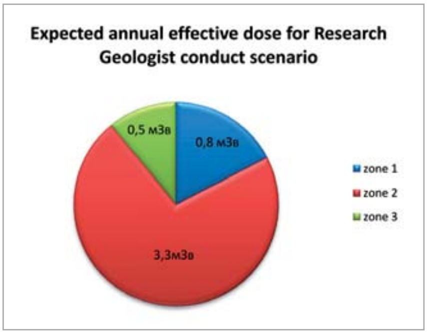
Figure 31. Expected annual effective dose for the agricultural scenario for the shepherd through major exposure pathways in Zones I, II, III of "Baitemir" field

The expected annual effective dose for the agricultural scenario of the shepherd through major exposure pathways from artificial radionuclides at specific activities in the surface soil layer does not exceed statutory limits and in Zone I will comprise ~ $9.8 \cdot 10^{-1}$ mSv, in Zone II - ~ $8.1 \cdot 10^{-1}$ mSv, in Zone III - ~ $2.4 \cdot 10^{-1}$ mSv. The main contribution to dose loads in Zones I and III is made by internal doses gained from foodstuffs (~$7.1 \cdot 10^{-1}$ mSv, ~$1.1 \cdot 10^{-1}$ mSv), in Zone II - internal dose from inhalation of radionuclides (~$6.2 \cdot 10^{-1}$ mSv). Contribution to the effective annual dose when incorporated with food for an adult is 73% in crop and 27% in livestock products. The main contribution to the expected annual dose gained with livestock products at average specific activities of radionuclides in surface soil is made by dairy products - 56%.

The histogram (Figure 32) shows assessed dose loads to personnel for the geological exploration scenario in the area, at average specific activities of artificial radionuclides in the surface soil layer.



a)



b)

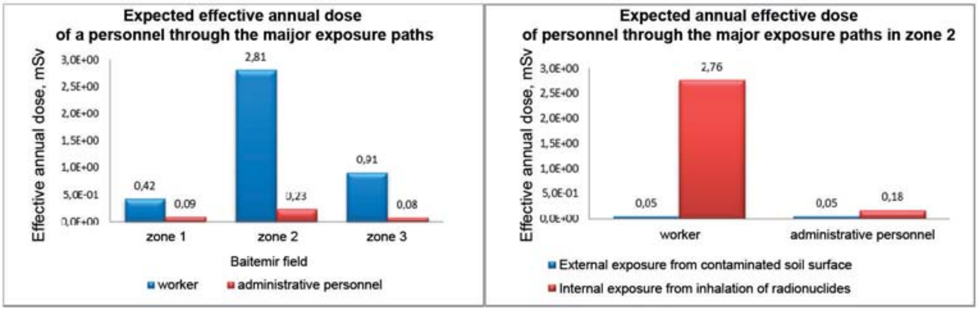
Figure 32. Expected annual effective dose for research scenario (geologist) through major exposure pathways in Zones I, II, III of "Baitemir" field

The expected annual effective dose to staff through major exposure pathways at average specific activities of artificial radionuclides in surface soils in the studied area for research scenario does not exceed the statutory limits and in Zone I will comprise ~ $5.0 \cdot 10^{-1}$ mSv, in Zone II ~ 3.3 mSv, in Zone III ~ $8.0 \cdot 10^{-1}$ mSv. The main contribution to the dose loads to personnel (geologist) in "Baitemir" field is made by internal dose from inhalation of radionuclides from the soil surface (99%), namely, radionuclide $^{238+239+240}$Pu.

The results of assessing the staff dose loads for industrial scenario (worker and administrative staff) in the area, at average specific activities of artificial radionuclides in surface soil layer are shown below (Figure 33).

Figure 34 shows that the worker may receive the highest dose load. The main contribution to the expected annual effective dose is made by internal dose from inhalation of radionuclides.

Expected annual effective dose to the staff for industrial scenario of a worker in Zone I will be ~ 0.6 mSv, in Zone II ~ 2.5 mSv, in Zone III ~ 0.4 mSv. Expected annual effective dose to the personnel for industrial scenario of administrative staff of the factory in Zone I will be ~ 0.1 mSv, in Zone II ~ 0.2 mSv, Zone III ~ 0.04 mSv. The main contribution to the dose load to staff is made by a dose from inhalation of radionuclides from the soil surface in Zone I - 89%, in Zone II - 99%, in Zone III - 95%.



a) b)

Figure 33. Expected annual effective dose for industrial scenario of personnel (worker and administrative staff) through major exposure pathways in Zones I, II, III of "Baitemir" field

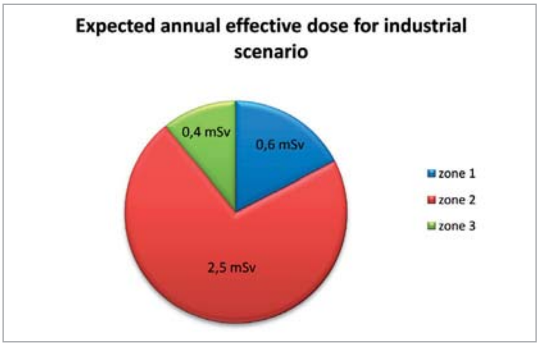


Figure 34. Expected annual effective dose for industrial scenario of a worker through major exposure pathways of "Baitemir" field in Zones I, II and III

CONCLUSION

The indicators in assessment of human radiation safety, in accordance with the Government Resolution #653 dated 31.06.2007, as well as the Radiation Safety Standards (NRB-99), and international standards (BSS) is **the value of effective dose.** According to the studies conducted in 2011, there were assessed the expected annual effective doses to personnel working in the studied area. The calculations were performed for the three Zones of the studied area with different levels of radioactive contamination.

During the calculation of dose loads to population and personnel at residing and carrying out activities on "Baitemir" field of the STS, the following results were obtained:

1. The expected annual effective dose to farmer and shepherd (agricultural scenario) through major exposure pathways from artificial radionuclides at average specific activities in the surface soil layer does not exceed statutory limits and in Zone I will comprise ~ $9.8 \cdot 10^{-1}$ mSv, in Zone II ~ $8.1 \cdot 10^{-1}$ mSv, in Zone III ~ $2.4 \cdot 10^{-1}$ mSv. The main contribution to dose loads in Zones I and III is made by internal dose gained from foodstuffs (~$7.1 \cdot 10^{-1}$ mSv, ~$1.1 \cdot 10^{-1}$ mSv), in Zone II - internal dose from inhalation of radionuclides ($6.2 \cdot 10^{-1}$ mSv).

2. The expected annual effective dose to personnel through major exposure pathways at average values of specific activities of artificial radionuclides in surface soils of the studied area for research scenario does not exceed the statutory limits and in Zone I will comprise ~ 0.8 mSv, in Zone II - ~ 3.3 mSv, in Zone III - ~ 0.5 mSv.
3. The expected annual effective dose to the personnel for industrial scenario of a worker in Zone I will be ~ 0.6 mSv, in Zone II - ~ 2.5 mSv, in Zone III - ~ 0.4 mSv. The expected annual effective dose to the personnel for industrial scenario of administrative staff of the factory in Zone I will be ~ 0.1 mSv, in Zone II - ~ 0.2 mSv, in Zone III - ~ 0.04 mSv. The main contribution to the dose loads to personnel is made by doses from inhalation of radionuclides from the soil surface in Zone I - 89%, in Zone II - 99%, in Zone III - 95%.
4. The assessments made on the dose loads to the population during their stay and activities in the studied area showed that the expected annual effective dose in Zones I, II and III does not exceed the basic dose limits of acceptable standards for the public (1 mSv/year), but the levels are quite high. On this basis, we can conclude that this area is not recommended to be transferred from the reserve lands to agricultural use.

The estimates of dose loads to staff for research and industrial scenarios for the workers exceed the basic dose limits of acceptable standards for the public (1 mSv/year). Therefore, when conducting any works it is recommended to classify the workers to category B.

Based on these results obtained, we may conclude that the lands, in accordance with the Land Code of the Republic of Kazakhstan, can be converted into industrial lands, transport, communication, defence and other non-agricultural use.

REFERENCES

1. Topical Issues in Radioecology of Kazakhstan [Semipalatinsk Test Site: Radio-ecological Situation of the Northern Lands]. [in Russian]
   Актуальные вопросы радиоэкологии Казахстана [Радиоэкологическое состояние "северной" части территории Семипалатинского испытательного полигона] / под рук. Лукашенко С.Н. – Вып. 1. – Павлодар: Дом печати, 2010. – 234с.: ил.- Библиогр.: С.224-231. - ISBN 978-601-7112-28-8.
2. Theoretical calculation of the quantities of artificial radionuclides - fission products during the explosions in salt domes of KOGCF and determination of trace concentration fissile actinoids in non-fissile materials by track technique: research report/ S. I. Mulgin. - Almaty: Institute of Nuclear Physics NNC RK, 1999. [in Russian]
   Теоретический расчет наработанных количеств искусственных нуклидов - продуктов деления при проведении взрывов в соляных куполах КНГКМ и определение микроконцентраций делящихся актиноиодов в неделящихся материалах с помощью трековой методики: отчет о НИР / рук. Мульгин С.И. – Алматы: ИЯФ НЯЦ РК, 1999.
3. Tutorial-procedure manual for radioecology and radioactive waste management for Kazakhstan – Almaty: JSC "Volkovgeology" [in Russian]

Учебно-методическое руководство по радиоэкологии и обращению с радиоактивными отходами для условий Казахстана / ред. Т.Е. Каткова. - Алматы: ОАО "Волковгеология", 2002. - 304 с.

4. INTERNATIONAL ATOMIC ENERGY AGENCY, Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments, IAEA -TECDOC-1616. – Vienna: IAEA, 2009.
5. Safety Assurance of the former Semipalatinsk Test Site. State Budgetary Program 038 "Radiation Safety": Research Report (informative) under the contract from 19.02.2010 № 4-20103 / IRSE NNC RK. [in Russian]
   Обеспечение Безопасности Бывшего Семипалатинского Испытательного Полигона Республиканская Бюджетная программа 038 "Обеспечение радиационной безопасности" : отчет о НИР (информационный) по договору № 4-20103 от 19.02.2010 / ИРБЭ НЯЦ РК; рук. Лукашенко С.Н. – Курчатов: ИРБЭ НЯЦ РК, 2010. -128с.
6. Temporary allowable levels for radionuclides in the units under tests of the Ministry of Agriculture of RK, not included in the list of the Ministry of Health of Kazakhstan. [in Russian]
   Временные допустимые уровни содержания радионуклидов в объектах контроля Минсельхоза РК, не вошедших в перечень Минздрава Республики, 22.02.94.
7. Agricultural Radioecology / the All-Union Academy of Agricultural Sciences of the Soviet Union. R.M. Aleksahina and N. A. Korneeva - Moscow, 1991. - P.57-58. [in Russian]
   Сельскохозяйственная радиоэкология / под ред. академиков ВАСХНИЛ Р.М.Алексахина и Н.А.Корнеева. – Москва, 1991. – С.57-58.
8. Sanitary rules and norms № 4.01.071.03 "Hygienic requirements for safety and nutritional value of food products": approved by the Order of Minister of Health of the Republic of Kazakhstan from June 11. 2003 № 447. [in Russian]
   Санитарные правила и нормы №4.01.071.03 "Гигиенические требования к безопасности и пищевой ценности пищевых продуктов": утв. приказом министра здравоохранения Республики Казахстан от 11 июня 2003 г. №447.
9. Methods for determining the content of artificial radionuclides plutonium-(239+240), strontium-90 in environmental media (soils, soil, sediment and plants). [in Russian]
   Методика определения содержания искусственных радионуклидов плутония-(239+240), стронция-90 в объектах окружающей среды (почвах, грунтах, донных отложениях и растениях). KZ.07.00.00471-2005.
10. Activity of radionuclides in bulk samples. The method of measurement for gamma – spectrometer: MI 2143-91. [in Russian]
    Активность радионуклидов в объемных образцах. Методика выполнения измерений на гамма - спектрометре: МИ 2143-91. - Введ. 1998-06-02. - Рег. № 5.06.001.98. – М.: НПО ВНИИФТРИ, 1991. - 17 с.
11. State sanitary-epidemiological rules and standards. Radiation Safety Standards (NRB-99). [in Russian]

Государственные санитарно-эпидемиологические правила и нормативы. Нормы радиационной безопасности (НРБ-99): СП 2.6.1. 758-99. - Введ. 2000 -01-01. – Алматы: Агентство по делам Здравоохранения РК, 1999. - 80с. – ISBN 9965-501-42-4.

12. Oatway W. B. Methodology for Estimating The Doses to Members of the Public from the Future Use of Land Previously Contaminated with Radioactivity / W. B. Oatway and F. Mobbs // Report NRPB W36 National Radiological Protection Board. – Great-Britain, 2003.
13. Brown J. FARMLAND: A dynamic model for the transfer of radionuclides trough terrestrial food chains / Brown J and Simmonds JR. // Chilton, NRPB – R 272. – 1995.
14. Minimal consumption rates of staple foods for different social groups in the Republic of Kazakhstan / / Ministry of Labour and Social Protection of 2005. № 307 / 1- p. [in Russian]
Минимальные нормы потребления основных продуктов питания для различных социальных групп населения Республики Казахстан // Министерство труда и социальной защиты населения РК от 2005г. № 307 / 1 –п.

"БАЙТЕМІР" КЕНОРНЫ АУМАҒЫНЫҢ РАДИОЭКОЛОГИЯЛЫҚ АХУАЛЫ

Стрильчук Ю.Г., Айдарханов А.О., Генова С.В., Каширский В.В., КундузбаеваА.А., Ларионова Н.В., Магашева Р.Ю., Паницкий А.В., Субботин С.Б., Топорова А.В.,Тоневицкая О.В., Яковенко Ю.Ю., Лукашенко С.Н.

ҚР ҰЯО Радиациялық қауіпсіздік және экология институты, Курчатов, Қазақстан

Мақалада Семей сынақ полигоны аумағында екі облыс - Павлодар және Шығыс Қазақстан облыстарының шекарасында орналасқан "Байтемір" кенорнының кешенді радиоэкологиялық зерттеу нәтижелері ұсынылған. Кенорны телімінің жалпы ауданы 40 км^2 құрайды. Жұмыс барысында қоршаған ортаның: құмдақтопырақ, ауа бассейні, өсімдік жамылғысы, жануарлар әлемінің радиациялық белгісі бойынша қазіргі радиоэкологиялық ахуалын бағалау орындалды. Кенорны аумағындағы табиғат ортасы нысандарындағы жасанды радионуклидтердің құрамы алғашқы термоядролық және екі гидроядролық сынақтарды жүргізу нәтижесіндегі радиоактивті түсулерге байланысты. Жасанды радионуклидтердің алаңдық таралуын талдау кезінде олардың тиесілі белсенділігінің жоғары мәндері бар аймақтар анықталды. Радиоактивті ластанудың деңгейі мен сипаты бойынша әрқайсысы үшін топырақ жамылғысындағы радионуклидтердің тиесілі белсенділігінің орташа мәндері анықталған үш аймақ анықталды. I және II аймақтардың аумақтары көп дәрежеде жасанды радионуклидтермен ластанған, ал III аймақты шартты таза аумақ деп санауға болады. ^{137}Cs және ^{90}Sr радионуклидтерінің тиесілі белсенділігінің максималды мәндері аумақтардың экологиялық жағдайын "салыстырмалы қанағаттанарлық жағдай" ретінде сипаттайтын деңгейлерден төмен. Радионуклидтердің топырақ жамылғысындағы, судағы және ауадағы, сондай-ақ жануар және өсімдік тектес азық-түлік өнімдеріндегі күтілетін құрамы рауалы деңгейлерден көп төмен. Табиғат ортасы мен азық-түлік өнімдеріндегі радионуклидтердің құрамы туралы деректер негізінде әр аймақ үшін тұрғындарға дозалық жүктемені бағалау жасалды. "Аса нашар" сценарий "жағдайы кезінде ластанған аумақ шегінде табиғи шаруашылық жүргізетін фермер күтілетін жылдық тиімді доза бір адамға 0.93 мЗв құрайды, бұл Радиациялық қауіпсіздік нормаларына сәйкес жылына 1 мЗв дозалар шегінен аспайды. Сонымен қатар егер күтілетін доза 0.3 мЗв/жыл асатын болса, аталған аумақ шектерінде тұрғындардың сәулеленуін шектеу мақсатында қорғау шараларын жүргізу қажет. ҚР қолданыстағы нормативтік база талаптарын ескере отырып барлық зерттелген аумақ шектеусіз пайдалануы мүмкін болғанымен, аталған аумақты жер қорынан ауылшаруашылық айналымына беру ұсынылмайды. Тұрғындарға дозалық жүктемені бағалау негізінде, егер зерттелген аумақ шегінде шаруашылық қызметті жүргізу жағдайында "Байтемір" кенорны аумағын өнеркәсіп, көлік, байланыс, қорғаныс, және басқа да шаруашылық емес тағайындауларға беру ұсынылады.

Түйін сөздер: "Байтемір" кенорны, ядролық сынақтар, радиоэкология, радиоактивті ластану, радионуклидтер, топырақтар, өсімдік жамылғысы, азық-түлік өнімдері, жүріс-тұрыс сценариі, жылдық тиімді доза

РАДИОЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ ТЕРРИТОРИИ МЕСТОРОЖДЕНИЯ "БАЙТЕМИР"

Стрильчук Ю.Г., Айдарханов А.О., Генова С.В., Каширский В.В., Кундузбаева А.А., Ларионова Н.В., Магашева Р.Ю., Паницкий А.В., Субботин С.Б., Топорова А.В.,Тоневицкая О.В., Яковенко Ю.Ю., Лукашенко С.Н.

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В статье представлены результаты комплексного радиоэкологического исследования месторождения "Байтемир", расположенного на территории Семипалатинского испытательного полигона в границах двух областей – Павлодарской и Восточно-Казахстанской. Общая площадь участка месторождения составляет 40 км^2. В ходе работ выполнена оценка современного радиоэкологического состояния окружающей среды: почвогрунтов, воздушного бассейна, растительного покрова, животного мира по радиационному признаку. Содержание искусственных радионуклидов в объектах природной среды территории месторождения обусловлено радиоактивными выпадениями в результате проведения первого термоядерного испытания и двух гидроядерных испытаний. При анализе площадного распределения искусственных радионуклидов выявлены зоны с повышенными значениями их удельной активности. По уровню и характеру радиоактивного загрязнения выделено три зоны, для каждой из которых были определены средние значения удельной активности радионуклидов в почвенном покрове. Территории I и II зон в большей степени загрязнены искусственными радионуклидами, а зону III можно считать условно чистой территорией. Максимальные значения удельной активности радионуклидов ^{137}Cs и ^{90}Sr ниже уровней, характеризующих экологическое состояние территорий как "относительно удовлетворительная ситуация". Содержание радионуклидов в растительном покрове, воде и воздухе, а также ожидаемое содержание в продуктах питания животного и растительного происхождения значительно ниже допустимых уровней. На основании данных о содержании радионуклидов в объектах природной среды и продуктах питания была сделана оценка дозовых нагрузок на население для каждой зоны. При условии "наихудшего" сценария "фермер, ведущий натуральное хозяйство в пределах загрязненной территории", ожидаемая годовая эффективная доза на человека составит 0.93 мЗв, что не превышает предел доз 1 мЗв в год, согласно Нормам радиационной безопасности. Вместе с тем, в случае, если ожидаемая доза превышает 0.3 мЗв/год, в пределах данной территории необходимо проводить защитные мероприятия с целью ограничения облучения населения. Несмотря на то, что с учетом существующих требований нормативной базы РК вся обследованная территория может использоваться без ограничений, переводить данную территорию из земель запаса в сельскохозяйственный оборот не рекомендуется. На основании оценки дозовых нагрузок на персонал в случае ведения хозяйственной деятельности в пределах исследованной территории предлагается перевести территорию месторождения "Байтемир" в земли промышленности, транспорта, связи, обороны и иного несельскохозяйственного назначения.

Ключевые слова: месторождение "Байтемир", ядерные испытания, радиоэкология, радиоактивное загрязнение, радионуклиды, почвы, растительный покров, продукты питания, сценарии поведения, годовая эффективная доза

УДК 577.4:553:504.064:539.16

CURRENT RADIOLOGICAL SITUATION AT "ESYMZHAL" DEPOSIT

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This paperreports on the radio-ecological research at "*Esymzhal*" deposit territory located in the south-western part of STS. The investigations established that the content of artificial radionuclides at the surface within the deposit is mainly caused by global fallout. At present the radiation situation at the deposit is stable and does not require special measures for radiation safety. The results show that on the surveyed area the population may stay without limit of time. However, due to close location of test sites with high levels of radioactive contamination, which can lead to a change in the radiation environment on the studied areas, it has been recommended to ensure radiation safety of staff and products, to create a radiation monitoring system, which provides control of the main probable routes of contamination to the territory of the deposit.

Keywords: Esymzhal, deposit, "*Degelen*" site, hydrogeology, radionuclide contamination, underground nuclear explosions, ^{40}K, ^{232}Th, ^{226}Ra, ^{137}Cs, ^{90}Sr, $^{239+240}$Pu.

INTRODUCTION

Esymzhal deposit is situated the south-western part of STS and includes three small deposits "Dauletpay", "Central-Southern" and "Northern" located close to each other (Figure 1).

Near the deposit the former test grounds "Sary-Uzen" (~ 20 km), "Aktan-Berli" (~ 30 km) and "Degelen" (~ 45 km) are located. These grounds have environmental objects subjected to considerable radioactive contamination which due to various reasons both natural (water transfer) and anthropogenic (unintentional transfer of radioactive materials) may cause changes in radiation situation on the considered deposits.

On the territory of the examined deposit manganese ores are mined. The ore is mined by the open-pit mining as the ore body is located close to the surface. The housing area for the working staff of "Temirtauskiy electrometallurgy enterprise" mining the deposit is also located near the deposits (Figure 2).

In 2010 the radio-ecological survey of the Esymzhal deposit was carried out. The aim of survey was to assess radio-ecological conditions in housing and working zones located on the territory of the deposit, to develop recommendations for organization of the radiation control system providing control of the most probable ways of radioactive contamination transfer.

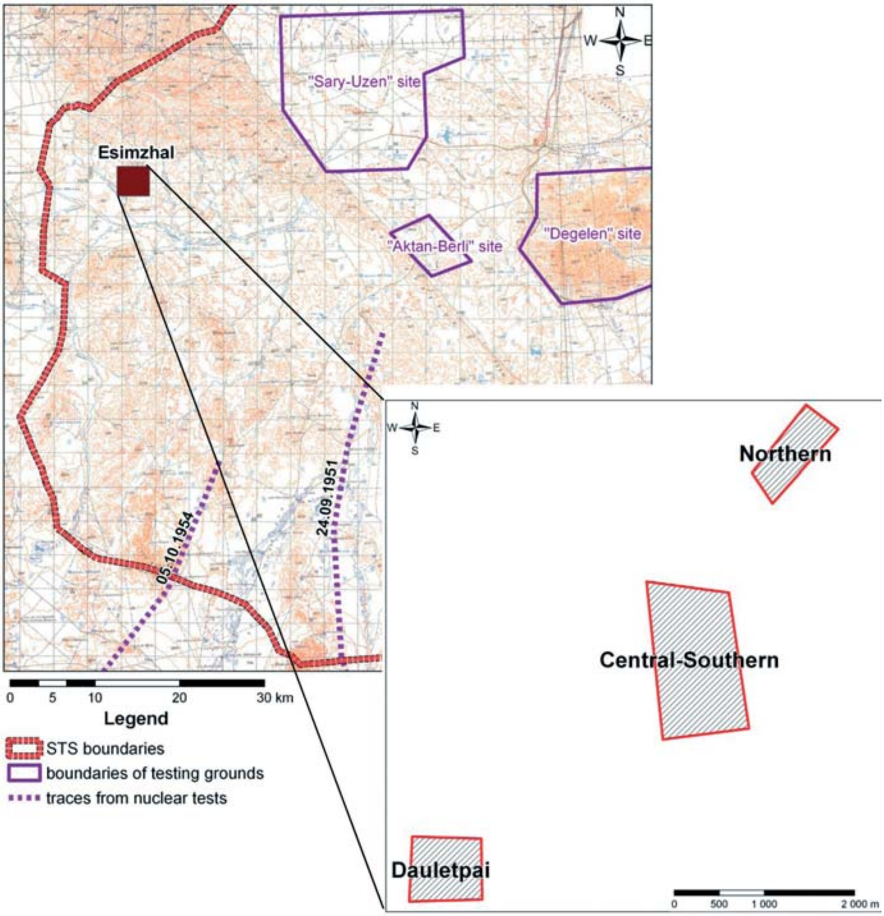

Figure 1. Location of Esymzhal deposit on the STS territory

1. EXPERIMENTAL PART

As the deposits "Central-Southern" and "Northern" are located close to each other, their examination was carried out according to a united scheme (Figure 2). Taking into account close location of all areas (at the STS scale), the mechanisms of radiation impact of the nearby test grounds on the deposit and the housing area must be the same. As a result, there was taken a decision on joint assessment of the influence of radiation–hazardous factors on the working staff and products produced by them.

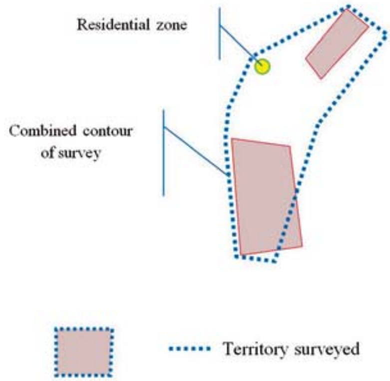

Figure 2. Examined area of the deposit

The survey included examination of distribution of radiation parameters (EDR and β-particles flux density) on the territory of the deposit and in the living quarters, studying of the concentration of natural and artificial radionuclides in the environmental samples (soil cover, surface and ground waters, air). The scheme of points where environmental samples were taken is shown in the figure (Figure 3).

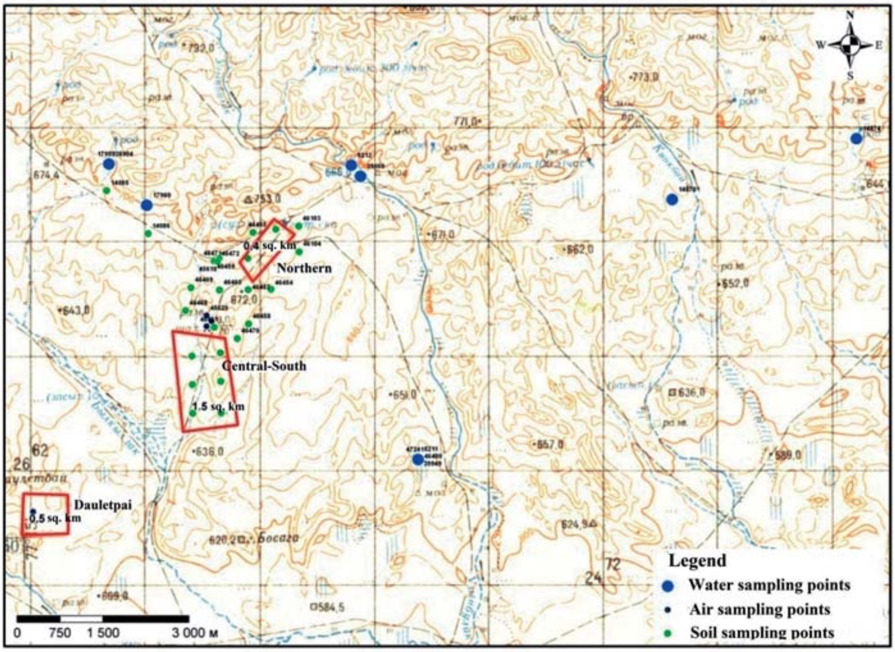

Figure 3. Scheme of environmental sampling points

1.1. Investigation of radioactive contamination of soil cover

Radiation parameters on the examined areas were measured in the nodal points of the survey network (for living premises - 1x5m, territory of the living zone – 10x5m, territory of deposits – 100x50m) and between the points in the "Search" regime according to the technique of gamma-background measurement on territories and in premises [1]. To estimate soil cover radioactive contamination, the samples of the surface soil layer were taken. The samples were taken with account for the relief of the area, location of natural and man-made objects, location of industrial and living areas, driveways and spots with high radiation background identified during pedestrian surveying. The scheme of points of sample taking is shown in the figure (Figure 4). The area of point sampling was 200 cm^2, depth 5 cm. The samples were taken and packed according to the requirements to taking soil samples for general and local contamination [2]. In all samples the concentration of natural (^{40}K, ^{232}Th, ^{226}Ra) and artificial (^{137}Cs, ^{90}Sr, $^{239+240}Pu$) radionuclides was determined.

1.2. Investigation of radioactive contamination of aquatic environment

The most probable source of radionuclide penetration into the aquatic environment on the examined area is radioactive contamination of the test ground "Sary-Uzen" [3]. Radioactive contamination of the aquatic environment is most probably caused by the artificial radionuclide ^{3}H. To estimate radionuclide composition of the aquatic environment samples of surface, ground waters and the water from the open-pit were taken. The sampling points are shown on the map (Figure 3). Water samples are placed in hermetic polyethylene vessels. The sample volume used to determine concentrations of artificial radionuclides ^{137}Cs, ^{90}Sr and $^{239+240}Pu$ was not less than 10 liters, for tritium – 1.5 liters. All in all, 8 water samples were taken; all 8 were analyzed for the presence ^{3}H, and in one sample concentration of all radionuclides was analyzed.

1.3. Studies of air radioactive pollution

The most probable sources of radionuclide penetration on the day surface are consequences of tests on the test ground "Opytnoye pole"(Experimental field), namely, radioactive traces of the test on 05.10.54 and radiation contamination on the test ground "Sary-Uzen" [3].

Long-term examinations of the STS territory [11] showed that even for large-area sources of radionuclide contamination of day surface such as "Opytnoye pole", considerable radioactive contamination of the atmosphere surface layer may be caused only by man-made dust (movement of cars and works causing rise of large amounts of dust) and by steppe fires. It is confirmed by the results of some targeted investigations which were made in Kurchatov, in northern and western parts of the STS. The results [4] confirmed the absence of significant radionuclide contamination of atmosphere in the region under different meteorological conditions.

As open-pit mining of the deposit is a type of work producing large amounts of dust, radioactive contamination of the air basin over the deposit territory was studied. To study the contamination of the air basin, samples of air aerosols were taken to determine contamination of the atmospheric air by natural and artificial radionuclides in the production zone and camp for workers.

EDR was measured in 912 fixed points and in "searching" regime between points. EDR values in the examined area varied from 0.11 to 0.21 µSv/h. EDR distribution was studied not only on the deposit but also detailed examination was made in the housing zone. EDR values in the housing zone varied from 0.10 to 0.15 µSv/h.

To study radioactive contamination of the atmospheric air, aerosol samples were taken. The samples were taken on the examined area with account for location of industrial objects, production and camping zones. To take samples a mobile air sampler "JAP-50" of productivity of 50-60 m^3/h was used. As a filter material we used cloth "Petryanova". The working area of the filter was 250 cm^2. Sampling lasted for 8 hours without interruptions. The volume of pumped air for each sample was 400 m^3.

1.4. Laboratory analyses of environmental samples

Concentration of natural and artificial radionuclides in all environmental samples was measured and analyzed using radiochemical, gamma-spectrometric and scintillation techniques according to [5–9].

2. INVESTIGATION RESULTS

2.1. Radiological situation on the deposit lands

EDR was measured in 912 fixed points and in "searching" regime between points. EDR values in the examined area varied from 0.11 to 0.21 µSv/h (Figure 4). EDR distribution was studied not only on the deposit but also detailed examination was made in the housing zone. EDR values in the housing zone varied from 0.10 to 0.15 µSv/h. In living and subsidiary premises EDR did not exceed 0.13 µSv/h. The density of β-particles on the territory of all examined areas was below the detection limit of used measuring devices (10 particles/min*cm^2).

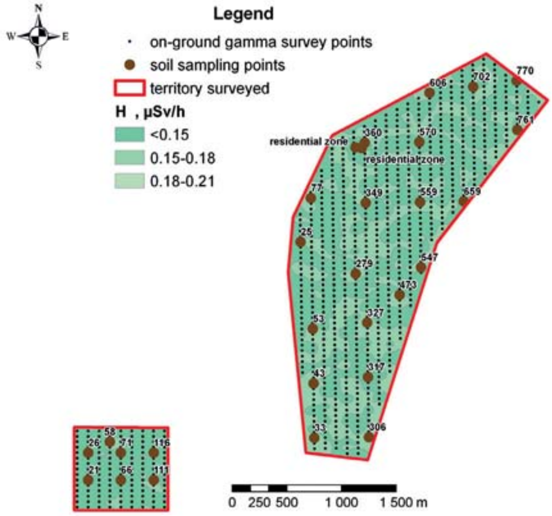

Figure 4. EDR distribution on the studied territory

To analyze EDR distribution, statistical data processing was made. The prepared sample included all measurements of radiation parameters. To make data processing valid we calculated anomalous values in the sample. As a result of calculations, 1 anomalous value – 0.21 μSv/h was removed. The analysis of EDR distribution showed that the results of measurements ranged from 0.11 to 0.19 μSv/h.

To estimate the values of the EDR distribution the variational curve below was drawn (Figure 5).

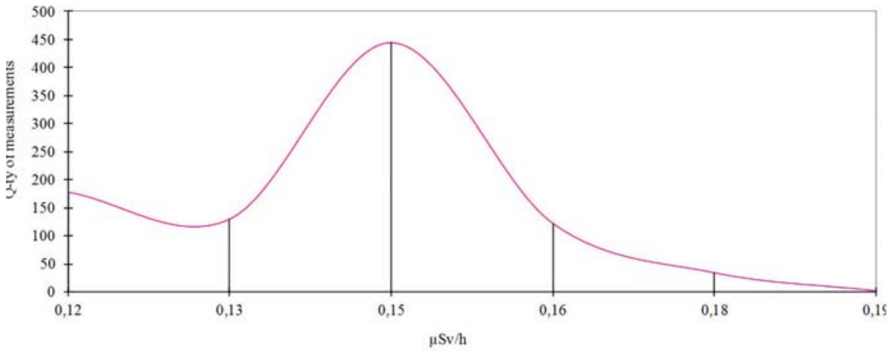

Figure 5. Variational curve for distribution of the number of EDR measurements.

The variational curve shows that the distribution of radiation parameters has a shape close to the normal (natural) distribution with a slight left asymmetry. The left asymmetry is caused by the detection limit of the used devices.

Based on the above results we can make a conclusion that the values of radiation parameters in the examined territory do not exceed the background values. EDR values measured in premises do not exceed the dose rate for the open air by more than 0.2 μSv/h, hence, according to NRB-99 no additional protective measures to reduce radiation background in premises are needed [1]. The distribution of radiological parameters does not have any anomalies and its shape is similar to that of the normal distribution. The dispersion of radiological parameters may be caused by many factors forming radiation situation (natural fluctuation of measured radiation parameters, increased activity of natural radionuclides in lithosphere, etc.) and uncertainty (error) of measurements.

2.2. Areal radionuclide contamination of soil cover

Soil samples taken on the "Esymzhal" territory were analyzed on the specific activity of natural and artificial radio-nuclides.

The concentration of radionuclides in soil according to the results of laboratory analyses and their distribution on the examined area are shown in figures (Figure 6, Figure 7). It should be noted that many measurements gave the radionuclide specific activity below the minimal detectable activity of used measuring devices, but to calculate average values we took the values of the detection limits, which gave artificial increase in the average value.

The concentration of natural radionuclides on the examined territory corresponds to the natural background of the area. Such concentration is typical of the soils of Semipalatinsk Test Site [2,3], no geochemical anomalies were discovered.

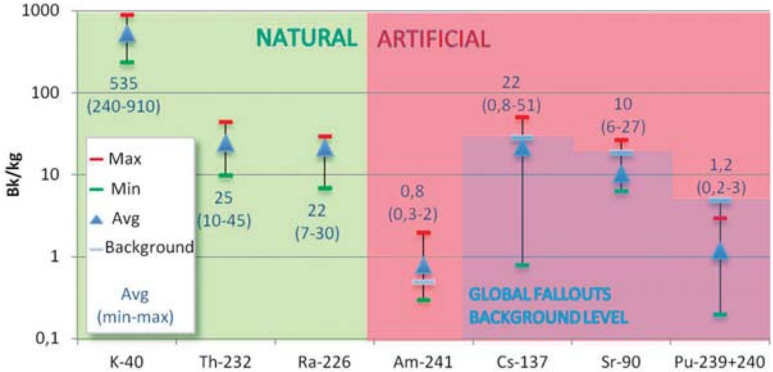

Figure 6. Concentration of natural and artificial radionuclides in soil.

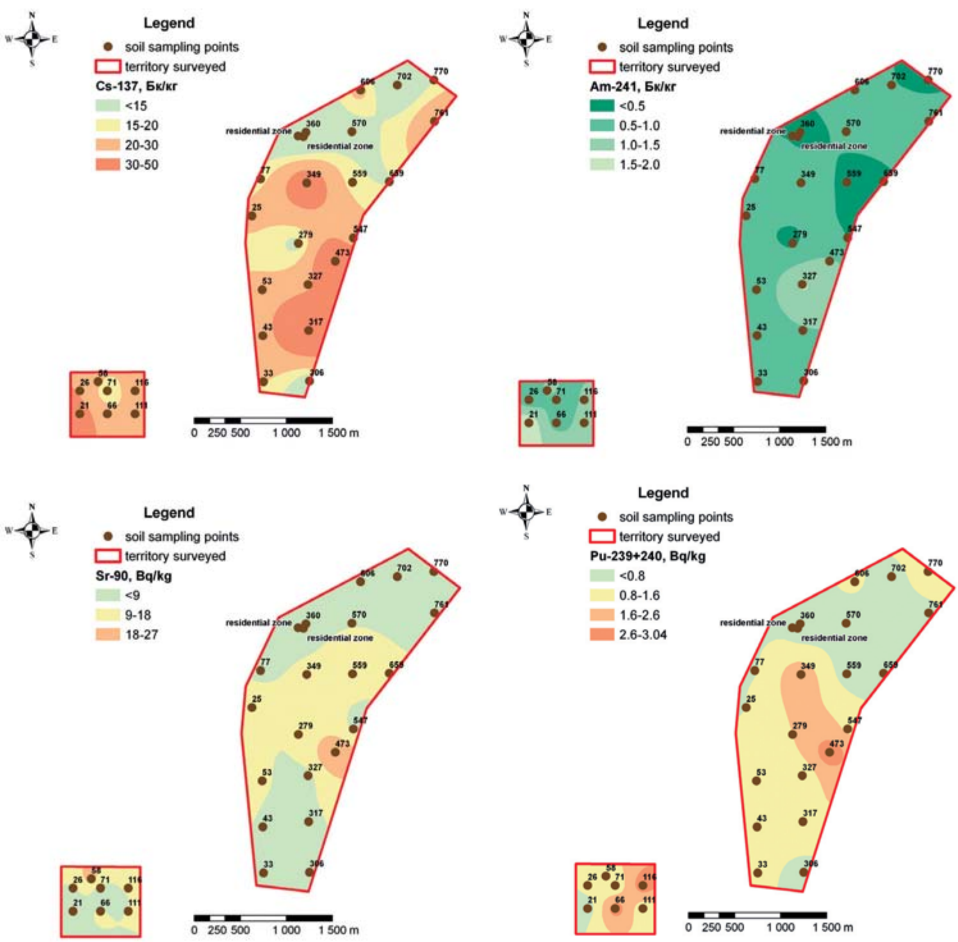

Figure 7. Maps of distribution of artificial radionuclides on the examined area

In order to estimate artificial radionuclide contamination of soil cover the obtained results were compared with the background of global fallouts [1, 2, 3, 4, 5, 6, 7, 8], criteria of estimation of ecological situation on the territories [9] (Table 1) and the Radiation Safety Standard state regulatory doc – Radiation Safety Standards NRB-99 [10].

Table 1.

Parameters of soil radioactive contamination [21]

Parameter	Characteristic		Relatively satisfactory condition
	Environmental disaster	Environmental emergency	
Radioactive contamination, Bq/kg*			
Cs-137	over 18,500	6,938 – 18,500	Up to 6,938
Sr-90	over 1,388	462 – 1,388	Up to 462
Pu (total isotopes)	over 46.3	23.1 – 46.3	Up to 23.1
Note: * specific activity calculated for the soil layer of 5 cm deep and soil density 1.6 kg/dm^3			

Specific activity of artificial radionuclides ^{137}Cs, ^{90}Sr, ^{241}Am and $^{239+240}$Pu in the 5-cm soil layer is considerably (2 orders of magnitude) lower than the permissible levels MZUA for such radionuclides and is at the background level of global fallouts [10]. The map shows areal distribution of radionuclides ^{137}Cs and ^{241}Am (Figure 7). According to criteria of assessment of ecological situation the examined territory can be referred to the category "relatively satisfactory situation". The results of radionuclide contamination studies showed that radiological situation on the territory of "*Esymzhal*" deposit is not hazardous in terms of radioactive contamination.

2.3. Radioactive contamination of aqueous environment

To study potential radioactive contamination of aqueous environment in the vicinity of the deposit, both ground and surface waters were studied. In 2011 samples of water inflow into the open-pit have been analyzed.

The results of laboratory analyses of water samples are presented in the tables (Table 2, Table 3).

Table 2.

Specific activity of tritium in water, kBq/kg

Sampling point No	Sampling location	2006	2007	2009	2010	2011
1	Well K-2	<0.17				<0.013
2	Well K-3	<0.17				
3	Well 5		<0.007			
4	Hollow			<0.007	<0.007	<0.012
5	Spring			<0.007	<0.007	<0.012
6	Draw well				<0.015	<0.012
7	Well 6		<0.007			
8	Open pit					<0.013

Table 3.

Specific activity of natural and artificial radionuclides in water, Bq/kg

Sampling point No	Sampling location	Sampling year	^{40}K	^{232}Th	^{226}Ra	^{241}Am	^{137}Cs	^{90}Sr	$^{239\ 240}$Pu
6	Draw well	2010	<5	<0.7	<0.3	<0.5	<0.2	<0.01	<0.006

The results of laboratory analyses showed that the concentration of artificial radionuclides did not exceed the minimal detectable activity of used measuring devices. Based on the above data we can make a conclusion that the specific activity of natural and artificial radionuclides in water is much lower that the intervention level for people in case of intake with water and food [10]. It is necessary to take into account that during mining of *Esyzhamal* deposit, the pit dewatering may cause formation and swelling of the depression cone (drainage cone), which can cover places where in the past underground nuclear explosions were made. Possibility of inflow of tritium-contaminated ground waters from "*Sary-Uzen*" test ground to the deposit ground waters is a real radiation hazard for employees working in the open-pit of the deposit. It must be taken into account that tritium is transferred with water and is not absorbed by rocks. Hence, when the depression cone swells, in rather short time periods tritium-contaminated ground waters can inflow into deposit waters. Under such conditions, on-line inspection and forecasting of groundwater quality can be made only based on the data of groundwater monitoring, which must take into account some probabilistic hydrodynamic features of formation of the water inflow into the open-pit.

2.4. Radioactive contamination of air basin

The results of laboratory analyses (Table 4) shows that the activity of artificial radionuclides in the air aerosol samples is lower than the minimal detectable activity of the measuring device and does not exceed the values of permissible volume activity both for the working staff (PVA_{work}) and the people living in the area (PVA_{pop}) [10].

Table 4.

Specific activity of natural and artificial radionuclides in samples of air aerosols

##	Sampling point	^{241}Am, Bq/m^3	^{137}Cs, Bq/m^3	^{226}Ra, Bq/m^3	^{232}Th, Bq/m^3	^{40}K, Bq/m^3	$^{239+240}$Pu, Bq/m^3	^{90}Sr, Bq/m^3
	Camp	$< 2\cdot10^{-4}$	$< 3\cdot10^{-4}$	$2\cdot10^{-3} \pm 5\cdot10^{-4}$	$< 2\cdot10^{-3}$	$1\cdot10^{-2} \pm 2\cdot10^{-3}$	$< 2\cdot10^{-3}$	$< 1\cdot10^{-3}$
	Open pit	$< 1\cdot10^{-4}$	$< 3\cdot10^{-4}$	$2\cdot10^{-3} \pm 4\cdot10^{-4}$	$< 1\cdot10^{-3}$	$1\cdot10^{-2} \pm 1\cdot10^{-3}$	$< 2\cdot10^{-3}$	$< 1\cdot10^{-3}$
	Open pit	$< 2\cdot10^{-4}$	$< 5\cdot10^{-4}$	$2\cdot10^{-3} \pm 5\cdot10^{-4}$	$< 2\cdot10^{-3}$	$1\cdot10^{-2} \pm 1\cdot10^{-3}$	$< 2\cdot10^{-3}$	$< 1\cdot10^{-3}$
	Open pit	$< 1\cdot10^{-4}$	$< 2\cdot10^{-4}$	$3\cdot10^{-3} \pm 5\cdot10^{-4}$	$< 1\cdot10^{-3}$	$1\cdot10^{-2} \pm 1\cdot10^{-3}$	$< 2\cdot10^{-3}$	$< 1\cdot10^{-3}$
PVA_{work}, Bq/m^3		2.5	$2.1\cdot10^{-1}$	$1.7\cdot10^{3}$	0.19	$3.8\cdot10^{3}$	$5.3\cdot10^{-1}$	$3.3\cdot10^{2}$
PVA_{pop}, Bq/m^3		$3.0\cdot10^{-2}$	$2.9\cdot10^{-3}$	27	$4.9\cdot10^{-3}$	31	$2.5\cdot10^{-3}$	2.7

In addition to estimation of air contamination with natural and artificial radionuclides we also studied equivalent equilibrium volume activity of daughter decay products (DDP EEVA) of radon isotopes. In 8 premises of the workers' camp the DDP EEVA values were measured for ^{222}Rn and ^{220}Rn. The DDP EEVA values for ^{222}Rn ranged from 23 to 68 Bq/m^3. All EEVA values for ^{220}Rn did not exceed the detection level of the device < 4 Bq/m^3. The EEVA for ^{222}Rn in the examined premises did not exceed the equivalent equilibrium volume activity of ^{222}Rn daughter decay products in the air of living premises, 200 Bq/m^{3}h according to NRB-99 [10].

CONCLUSION

This research enabled to obtain distribution of radiation parameters in the examined area and to study characteristics of radionuclide contamination of soil cover, air and aquatic environment.

At the present time radiation situation in the neighborhood of the deposit is stable and does not require taking of any special radiation safety measures. The obtained results show that people can stay on the examined area without any time limitations.

However, it should be noted that close location of the former test grounds with high levels of radioactive contamination, which due to different natural (dust and water transfer) and man-caused (unintentional transfer of radioactive materials) reasons, may cause changes in the radiation situation in the studied area. To provide radiation safety of the staff and products, it is necessary to create a radiation control system envisaging control of the most probable ways of radioactive contamination transfer to the territory of the deposit.

REFERENCES

1. Методика измерения гамма – фона территорий помещений: утв. Зам. Главного Государственного санитарного врача РК, 1997.
   A method for measurements of gamma-background in premises approved by Deputy Chief State Sanitary Medical Officer RK, 1997. – [in Russian].
2. ГОСТ 17.4.3.01-83. Охрана природы. Почвы. Общие требования к отбору проб. - Введ. 1984-01-07. // Сборник. Охрана природы. Почвы. – М.: Изд-во стандартов, 1998. – С. 29-31.
   State Standard GOST 17.4.3.01-83. Nature protection. Soils. General requirements to sampling. Est. 1984-01-07. Official edition, M: Standards – 1998, pp29-31.
3. Семипалатинский полигон. Обеспечение общей и радиационной безопасности ядерных испытаний / под ред. Логачева В.А. – Москва, 1997.
   Semipalatinsk Test Site. General and Radiation Safety Assurance at Nuclear Testings. /ed. by Logachev V.A. – Moscow, 1997.
4. Комплексные исследования радиоактивного загрязнения системы атмосфера-подстилающая поверхность и оценки радиационных рисков для населения Семипалатинского региона: Технический отчет по проекту МНТЦ К-928 / рук. Артемьев О.И. – Курчатов: ИРБЭ, 2005-2006.
   Complex studies of radioactive contamination in the system atmosphere-underlying surface and assessment of radiological risks for population of Semipal-

atinsk region: technical report for the ISTC Project k-928 / Man. Artemiev O.I. – Kurchatov: IRSE, 2005-2006.
5. Методика определения содержания искусственных радионуклидов плутония-(239+240), стронция-90 в объектах окружающей среды (почвах, грунтах, донных отложениях и растениях): KZ.07.00.00471-2005.
A method for determination of content of artificial plutonium and strontium radionuclides (Pu-239+240, Sr-90), in environmental samples of soil, bottom sediments and vegetation: KZ.07.00.00471-2005
6. Активность радионуклидов в объемных образцах. Методика выполнения измерений на гамма - спектрометре: МИ 2143-91. - Введ. 1998-06-02. - Рег. № 5.06.001.98. – М.: НПО ВНИИФТРИ, 1991. - 17 с..
Activity of radionuclides in volumetric samples. A method for gamma-spectrometry measurements: : МИ 2143-91. - Est. 1998-06-02. - Register № 5.06.001.98. – M: 1991. - 17 p.
7. Качество вода – определение активности трития, соответствующей данной концентрации – жидкостной метод сцинтилляционного счета: ISO 9698:1989 (E).
Water quality -- Determination of tritium activity concentration -- Liquid scintillation counting method: ISO 9698:1989.
8. Методика определения содержания искусственных радионуклидов плутония (239+240), стронция-90, цезия-137 в природных водах: KZ.07.00.00732-2007.
A method for content determination of plutonium-239+240, strontium-90 radionuclides in environmental waters. KZ.07.00.00732-2007.
9. Методика выполнения измерений активности радионуклидов плутоний-239,240 в счетных образцах, приготовленных из проб объектов окружающей среды". – М.: ФГУП "НПО Радиевый Институт им. В.Г.Хлопина.
A method for activity determination of plutonium-239, 240 radionuclides in environmental samples. M., Khlopin V.G. Radium Institute.
10. Нормы радиационной безопасности (НРБ-99): СП 2.6.1. 758-99; ввод. в действие 01.01.2000. – Алматы: Агентство по делам Здравоохранения РК, 1999. - 80с. – ISBN 9965-501-42-4.
Radiation Safety Standards State regulatory document (NRB-99).
11. Актуальные вопросы радиоэкологии Казахстана [Радиоэкологическое состояние "северной" части территории Семипалатинского испытательного полигона] / под рук. Лукашенко С.Н. – Вып. 1. – Павлодар: Дом печати, 2010. – 234с. - ISBN 978-601-7112-28-8.
Topical Issues in Radioecology of Kazakhstan [Radiological conditions of the Northern part of Semipalatinsk Test Site] / ed.by Lukashenko S.N. – Issue 1. Pavlodar: Printing House "Dom Pechati", 2010 – 234pp. - ISBN 978-601-7112-28-8.
12. Актуальные вопросы радиоэкологии Казахстана [Сборник трудов Института радиационной безопасности и экологии за 2007 – 2009гг.]. – Вып. 2. – Павлодар: Дом печати, 2010. – 528 с. - ISBN 978-601-7112-32-5.

Topical Issues in Radioecology of Kazakhstan [Proceedings of the Institute of Radiation Safety and Ecology for 2007-2009]. Issue 2. Pavlodar: Printing House "Dom Pechati", 2010 – 528pp. - ISBN 978-601-7112-32-5.

13. Василенко И.Я. Чернобыль и проблемы радиобиологии / И.Я. Василенко. -2001.
Vasilenko I.Ya. Chernobyl and problems of radiobiology. 2001.
14. Давыдов М.Г. Радиоэкология. Избранные главы / М.Г. Давыдов.
Davydov M.G. Radioecology. Selected chapters.
15. Источники, эффекты и опасность ионизирующей радиации. Доклад на Генеральной Ассамблее ООН за 1988г. - М., 1992.
Sources, Effects and Risks of Ionizing Radiation 1988 Report to the UN General Assembly.
16. Павлоцкая Ф.И. Миграция радиоактивных продуктов глобальных выпадений в почвах / Ф.И. Павлоцкая. - М.: Атомиздат, 1974.
Pavlotskaya F.I. Migration in soil of radioactive products from global fallouts. / M.: Atomizdat, 1974.
17. Глобальные выпадения и человек. – М.: Атомиздат, 1974.
Global fallouts and people. / M.:Atomizdat, 1974.
18. Моисеев А.А. Цезий – 137 в биосфере / А.А. Моисеев, П.В. Рамзаев. - М.: Атомиздат, 1975.
Moiseyev A.A., Ramzayev P.V. Cesium-137 in biosphere. / M.: Atomizdat, 1975.
19. Бонина Т.А. Анализ некоторых результатов долгосрочного радиоэкологического мониторинга территории Республики Беларусь / Бонина Т.А.[и др.].
Bonina T.A. et al. Analysis of certain outcomes from expensive radioecological monitoring of the territory of Byelorussia.
20. Чернобыль. Радиоактивное загрязнение природных сред / под ред. Ю.А. Израэля. - М.: Гидрометеоиздат, 1990.
Chernobyl: Radioactive contamination of the environment. / Ed. byIsrael Yu.A. – M.: Hydrometeoizdat, 1990.
21. Постановление Кабинета Министров РК № 653 от 31 июля 2007 г. "Об утверждении критериев оценки экологической обстановки территорий".
Republic of Kazakhstan Cabinet of Ministers Decree #653 from July 31, 2007 "About affirmation of criterions for assessment of ecological conditions of lands."

"ЕСІМЖАЛ" КЕНОРНЫНЫҢ ҚАЗІРГІ УАҚЫТТАҒЫ РАДИОЭКОЛОГИЯЛЫҚ ХАЛ-АХУАЛЫ

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Бұл жұмыста, ССП аумағының оңтүстік-батыс бөлігінде орналасқан "Есімжал" кенорнының аумағына жасалған радиоэкологиялық зерттеулердің деректері келтірілген. Жасалған зерттеулердің нәтижесінде, кенорнындағы аумақтың беткі қабатындағы техногенді радионуклидтердің құрамы негізінен, ғаламдық түсулерге байланысты шартталған. Қазіргі уақытта кенорнындағы радиациялық жағдай тұрақты және радиациялық қауіпсіздік бойынша арнайы шараларды ұйымдастыруды қажет етпейді. Алынған нәтижелерден көретініміз, зерттелген аумақта тұрғындар шектеусіз уақыт бойында жүруіне болады. Алайда, зерттелген аумақтың радиациялық жағдайының өзгеруіне алып келуі мүмкін радиоактивті ластану деңгейі жоғары сынақ алаңдары жақын орналасуына байланысты, қызметкерлердің және шығарылатын өнімнің радиациялық қауіпсіздігін қамтамасыз ету үшін, кенорнының аумағына радиоактивті ластанудың түсуі болжанған негізгі жолдарын бақылауды қамтамасыз ететін радиациялық бақылау жүйесін құру ұсынылған.

Түйін сөздер: Есімжал, кенорны, "Дегелең" алаңы, гидрогеология, радионуклидті ластану, жерасты ядролық жарылыстар, ^{40}K, ^{232}Th, ^{226}Ra,^{137}Cs, ^{90}Sr, $^{239+240}$Pu.

СОВРЕМЕННОЕ РАДИОЭКОЛОГИЧЕСКОЕ СОСТОЯНИЕ МЕСТОРОЖДЕНИЯ "ЕСЫМЖАЛ"

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В настоящей работе представлены данные радиоэкологических исследований на территории месторождения "Есымжал", расположенного в юго-западной части территории СИП. В результате проведенных исследований установлено, что содержание техногенных радионуклидов на дневной поверхности территории месторождения обусловлено, в основном, глобальными выпадениями. В настоящее время радиационная обстановка на участке месторождения стабильная и не требует принятия специальных мер по радиационной безопасности. Полученные результаты показывают, что на обследованной территории население может находиться без ограничения по времени. Тем не менее, в связи с близким расположением испытательных площадок с высокими уровнями радиоактивного загрязнения, которое может привести к изменению радиационной обстановки на изученных территориях, рекомендовано для обеспечения радиационной безопасности сотрудников и производимой продукции создание системы радиационного контроля, предусматривающей контроль основных вероятных путей поступления радиоактивного загрязнения на территорию месторождения.

Ключевые слова: Есымжал, месторождение, площадка "Дегелен", гидрогеология, радионуклидное загрязнение, подземные ядерные взрывы,^{40}K, ^{232}Th, ^{226}Ra,^{137}Cs, ^{90}Sr, $^{239+240}$Pu.

УДК 577.4:504.75.05:615.849:539.16

ON THE PROBLEM OF RECONSTRUCTION OF DOSES TO PEOPLE LIVING AROUND THE SEMIPALATINSK NUCLEAR TEST SITE

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The paper reports on the assessment of doses to the population exposed to radiation caused by nuclear weapon testing at the Semipalatinsk Nuclear Test Site. Sarzhal village is taken as a model; it is located in the range of the nuclear explosion fallouts, the population of which goes to the site during their work. Radionuclides content was investigated in the bodies of people using indirect methods (determination of radionuclides in urine), direct studies with body counter, as well as estimation of cumulative external doses in tooth enamel by EPR and determination of number of chromosomal aberrations.

Assessment of the cumulative external doses in tooth enamel by EPR dosimetry indicates heterogeneity of the population and likelihood of additional exposure of individuals from other sources of ionizing radiation. Assessment of cumulative dose by the method of studying chromosomal aberrations indicates increased, compared with the control, detection level of markers of radiation exposure in the population of Sarzhal villagers, upon that no link was found between frequency of detection of chromosomal aberrations and duration of residence in the territory.

Given the long time passed, insufficient information about radiation environment in the locality and on individual absorbed doses, more sensitive detection methods are to be used for determination of internal radionuclides content and for the choice of persistent biological markers of radiation exposure.

Keywords: retrospective dose assessments, Semipalatinsk Test Site, WBC, artificial radionuclides, cesium-137. americium-241. plutonium isotopes, tritium, EPR dosimetry

INTRODUCTION

Situation analysis. Issues of control of radioactive substances intake into human body and their contents have always been important in radiation protection. This is because radioactive substances can be accumulated in body and re-distribute in tissues reaching in some specific organs the levels which may be unsafe for human health. Development of reliable intake assessment methods and assessment of biological effects from radioactive substances in human body is fundamental in minimizing the consequences from exposure of the population, its medical and social rehabilitation.

The issue of dose reconstruction is of particular importance for people living within former Semipalatinsk Nuclear Test Site (STS) impact zone, due to temporal remoteness from the exposure episodes and lack of comprehensive information about radiation environment of the past years, possibility of additional exposure from medical treatment, economic activities in the territories contaminated with radionuclides. Since long time has elapsed after the nuclear tests, currently the major threat is internal human exposure from food and air inhaled.

Upon that currently there is no any method that would allow reliably determining individual cumulative effective doses. Only a combination of different methods will bring us close to the estimation of cumulative doses and to assess the potential risk for human health. To solve the problems of radiation dose reconstruction, currently the following is used: methods for determining internal contents of radioactive substances in body, assessment of external cumulative doses by EPR of tooth enamel, methods of biological indication of radiation exposure based on identification of cytogenetic markers.

Review of dosimetry methods. The major dose-forming artificial radionuclides today at STS are ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}Pu$ and ^{3}H. Study of contents for each of these radionuclides in human body requires use of appropriate methods.

Internal contamination with the radionuclides ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}Pu$ and ^{3}H is usually assessed by indirect methods – analysis of such biological samples as blood, hair, saliva, exhaled air, urine, feces, assessing contents of radionuclides in body. In actual practice, most often urine is analysed. A weakness of the method is dependence of results on the physical and chemical properties of the radioactive compounds, deposition and excretion of radionuclides, functional characteristics of the individual.

Compared with the method for indirect assessment of radionuclides content in biosubstrates, a method of direct measurements using a whole body counter (WBC) makes it possible to determine internal doses with the least error. The WBC allows determining the low specific activities of radionuclides in human body at different body mass and physique of patient and carrying out intravital determination of incorporated gamma-emitting radionuclides in human body. However, in case of $^{239+240}Pu$, ^{90}Sr - alpha- and beta-decayers, the WBC cannot determine activities of these radionuclides.

Internal doses, based on determination of radionuclides in human body, are calculated using the IAEA recommended biokinetic models – mathematical models describing intake, absorption and retention of radionuclides in various organs and tissues of body and subsequent excretion by different ways.

When restoring individual absorbed doses from external gamma radiation in residents of the regions affected by emergency situations (radioactive contamination of the environment caused by uncontrolled accidents and disasters, effects of ionizing radiation on the population caused by nuclear tests), a dosimetry method is employed using electron paramagnetic resonance (EPR). The basis of this method is quantitative determination of radiation defects in tooth enamel – the most mineralized and only non-metabolizing tissue of human body. The main weakness of the EPR method is the need in tooth extraction, and tooth should have sufficient amount (about 100 mg) of healthy enamel. Another drawback is a high complexity of analysis, very high cost of basic equipment – the EPR spectrometer and severe skill requirements to the staff.

During the retrospective dosimetry carried out long time after irradiation, a biological dosimetry method may serve as an addition to physical dosimetry. In this respect the promising is an analysis of stable chromosome aberrations, frequency of which is stable for a long time after irradiation. Effects of age of genome stabilization, as well as a physiological process named radiation adaptive response (RAR) under small doses of radiation are also described in literature. Essence of this phenomenon lies in the fact that preliminary exposure to low doses reduces the sensitivity of an object to a subsequent damaging effect of high doses of ionizing radiation [25]. Thus, dosimetry method based on the accountancy of the frequency of chromosomal aberrations depends on the individual constitutional peculiarities and does not allow assessing the cumulative doses.

Accordingly, the objective of this study was to assess and develop a methodology for an integrated approach to dose reconstruction of the population living within Semipalatinsk Nuclear Test Site impact zone, and to obtain evidence about contents of artificial radionuclides in bodies of people of the selected cohort.

1. MATERIALS AND METHODS

The works were carried out by the Institute of Radiation Safety and Ecology (IRSE) NNC RK in cooperation with the Institute of General Genetics and Cytology (IGG and C), Almaty, and the Institute of Nuclear Physics (INP) NNC RK, Almaty, from May to October 2010.

The first stage was to develop a questionnaire with questions that reflect radiation pathway, social status, professional occupation, nutrition, living habits, medical and genetic history, questionnaire survey and selection of persons to be examined.

At the second stage the respondents were delivered to the Institute of Radiation Safety and Ecology (IRSE) in Kurchatov, where they were examined during three days. Biological materials were sampled in accordance with hygienic requirements. All the patients were examined by the dentist, during the examination sanitation of the mouth and tooth extraction were carried out. The extracted molars were sent to the INP NNC RK to be studied by EPR dosimetry method. Blood was sampled in a treatment room of Kurchatov city hospital for cytogenetic studies. Urine was sampled for radiochemical analysis during three days. Radiochemical studies and measurements on the WBC were carried out in the background laboratories of the IRSE used to analyze only background samples to eliminate any of accidental contamination.

During the entire period of residence in Kurchatov, the examined people ate in the dining room of IRSE. It was assumed that during this time tritium would be excreted with urine, so the food and water used in the dining room for cooking were preliminarily analysed for content of tritium. Based on measurements both in food and water its content was below the instrumentation detection threshold.

1.1. Subject of the research

Given the objectives of the study, the surveyed group, by the results of the preliminary survey, included the persons born before the year of 1949 (primary episode), as well as born, and who came to the territory after 1962. Among the respondents 50 people were selected to assess the doses.

Breakdown of the examined people by individual characteristics is presented in Tables 1–3.

Table 1.

Breakdown of the examined individuals by sex and age

Age	Total amount	Men	Women
30-40 years old	1	1	
41-50 years old	9	5	4
51-60 years old	17	14	3
60 years and older	23	18	5
Total	50	38	12

Table 2.

Breakdown of the examined individuals by residence periods in inhabited locality

Age	Total amount	1949-1962		1963-1992		after 1993	
		Men	Women	Men	Women	Men	Women
30-40 years old	1			1			
41-50 years old	9	5	2		1		1
51-60 years old	17	14	2		1		
60 years and older	23	18	3		1		1
Total	50	37	7	1	3		2

Table 3.

Breakdown of the examined individuals by professional occupation

Occupation	Total amount	Men	Women
Agricultural activities	32	30	2
Employees	11	6	5
Unemployed	7	2	5
Total	50	38	12

1.2. Assessment of internal doses using indirect methods

1.2.1. Determination of radionuclides in urine by radiochemical method

Urine of the examined individuals was used as a bio-substrate. The urine was sampled within 72 hours daily. Daily urine was collected in a clean plastic container with a tight screw cap. The average daily amount of excretion was about 1,500 ml. For preservation of samples we used concentrated nitric acid – 80 ml of acid per 1.5 litres of sample. The samples were stored in a refrigerator for 3 days at a temperature of 0–4^0 C.

From each daily sample, 200 ml of aliquot was taken to determine tritium content. Next, the taken daily samples were combined into one. The total volume of the sample, thus, was about 4 litres in three days. For determination of ^{3}H in urine the samples were distilled with a strong oxidant ($KMnO_4$) on a rotary evaporator. The measurements were performed on the beta-spectrometer TriCarb-2900 in accordance with the manual [3].

Using a gamma-spectrometric analysis we determined contents of ^{137}Cs and ^{241}Am in the urine, preliminary physical concentration (evaporation) of samples was carried out to increase the limits of detection. The measurements were performed in the geometry of a plastic cylindrical container with a tight screw cap on the three γ-spectrometers manufactured by Canberra Co.: a broadband detector VE5030 and VE3830 (measurement time is 24 hours), as well as coaxial detector GX2020 (measurement time is 12 hours). The measurement was carried out in accordance with certified method [2].

The gamma-spectrometric analysis was followed by radiochemical determination of ^{90}Sr and $^{239+240}Pu$. To destruct the organic component of urine an acid ("wet") ashing of samples was used and subsequent chemical concentration in accordance with method [4].

1.2.2. Calculation of internal doses

Calculation of dose loads by the results of indirect determination of radionuclides used the methods presented in the publications of the IAEA and the ICRP [5–9]. These methods for calculating the dose loads, listed in the publications, are used to calculate the doses after a long period of time that has elapsed since exposure. These guidelines can be used to assess the dose loads to the population exposed to ground nuclear tests at STS during the years of 1949-1963. To assess the radionuclide intake into body, an analysis of excreta (urine or feces) is used to take into account the intake scenarios, biokinetic models of behaviour, as well as data on the contents of radionuclides in the excreta and time elapsed since intake into the organism. The method for calculation of doses to the population living within STS zone is described in detail in reference [10].

The examined population may be characterized by two main models of radionuclides intake into body: peroral and inhalation. To assess the radionuclide intake into body an analysis of excreta (urine or feces) is employed to use the data on the contents of radionuclide in the excreta and the time elapsed since intake into organism.

In accordance with the determined intake an expected effective dose for the period since the intake is calculated as follows:

$$E = \frac{M}{m(t)} e(g)_j$$

where: $e(g)_j$ – dose coefficient for the radionuclide j;
M – measured absolute concentration of the radionuclide in the daily excreta, Bq;
m(t) – fraction of radionuclide which remains in body (for the direct measurement) or excreted from body (for indirect measurement) by the time *t* after intake. The value of m(t) depends on the radionuclide biokinetics, i.e. its chemical form, intake pathways and the time elapsed after intake, usually measured in days.

Since M is a value derived from the research of a particular radionuclide in urine, the emphasis should be focused on the proper selection of dose coefficient $e(g)_j$ and the value of m (t), which are contained in the ICRP publications, but depend on many factors. These quantities are determined by biokinetic model of the radionuclide behaviour in body and excretion from it.

1.3. Assessment of internal doses using direct methods for determining radionuclides

1.3.1. Determination of radionuclides activity in human body using the WBC (direct method)

The studies were carried out in the ordinary room using a semiconductor detector based on high purity germanium. The examined was laid horizontally on a couch; the radiation detector was set under the couch in the projection of the chest. To protect against external background of natural radionuclide the detector is surrounded by shady shielding. A phantom was used to calibrate the WBC detection efficiency.

To manufacture the phantom, plastic containers were used, which were placed on the couch, imitating human contour. The containers were filled with a solution with known contents of ^{137}Cs and ^{241}Am, prepared by radiochemical separation of these radionuclides from the soil samples, taken from the STS territory. The total volume of the containers is 56 l. Activities of ^{137}Cs and ^{241}Am in the phantom on average was 4.9 ± 0.2 Bq/l. The registration efficiency for the results of three measurements of the phantom was for ^{137}Cs – 0.017 % and for ^{241}Am – 0.104 %.

To record the Compton scattering of gamma-rays from ^{40}K contained in the body of every person, we constructed experimental dependences of background count rise in the registration of ^{241}Am and ^{137}Cs of the activity of ^{40}K. Similar dependences were constructed for the rise of background count in the registration of ^{241}Am on the activity of ^{137}Cs in the test object. The result of the measurement is the amplitude spectrum, which is processed in a semiautomatic mode with software and comes to determining the total absorption peak for ^{137}Cs and ^{241}Am. Activities of incorporated radionuclides are calculated according to:

$$A = \frac{S}{\varepsilon \times m \times \eta \times t}$$

where: A - specific activity, Bq/kg,
S - total absorption peak in the registration window of the radionuclide,
ε - registration efficiency of the radionuclide, calculated based on the results of phantom measurements,
m - weight of the examined, kg,
η - quantum yield of radionuclide gamma-line,
t - spectrum acquisition time, sec.

Minimal detectable activity at spectrum acquisition time of 60 min and body weight of 80 kg of the examined was ^{241}Am – 240 Bq and for ^{137}Cs - 200 Bq.

1.3.2. Assessment of dose loads at internal intake of the radionuclide ^{137}Cs using direct methods

In calculating the average annual individual effective doses using the data of the WBC measurements there was accepted a model of equilibrium content of ^{137}Cs in the body, when the average value during the year of the daily intake of radionuclide corresponds to its average daily excretion. The average annual individual effective dose is determined according to [25, 26]:

$$E = k_d \cdot \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{Q_i}{M_i}$$

where: k_d – dose coefficients for adults equal to 2.3 mSv*kg/kBq*year;
Qi – content of ^{137}Cs in the body of i-th person according to the WBC-measurements, kBq;
Mi – weight of i-th person, kg;
n – number of the examined on the WBC.

At the moment, there are methods for calculation of individual effective doses using data of WBC from ^{241}Am at its one-shot intake. However, due to lack of methodology for calculation of individual effective doses using data of WBC from ^{241}Am at its chronic intake, to assess the expected dose loads at peroral and inhalation intake of radionuclide ^{241}Am it was decided to use the software MONDAL3 developed by the IAEA.

1.4. Assessment of external dose with electron paramagnetic resonance (EPR)

Teeth for EPR analyses and determination of the absorbed doses were prepared in compliance with the standards of RF [14], taking into account recommendations [15] and recent experience obtained within the international experiment "Intercomparison" organized under the aegis of the IAEA. In EPR analysis we used teeth pulled out for medical reasons. A prepared and disinfected tooth was accompanied by questionnaire form, filled in by a dentist. The tooth was cut by jet of water into 2 parts – crown of tooth and root. Crown of tooth was used for analyses.

To assess the quality and classify the tooth enamel samples for total absorbed dose reconstruction using the EPR method, the teeth samples were pre-treated in an ultrasound bath. The ultrasound treatment was carried out in 20% solution of NaOH at empirically chosen power of the ultrasonic bath. To remove extraneous paramagnetic centers and the alkali residue, the tooth was treated by acetic acid solution and thoroughly washed with distilled water. Then, a dental drill completely removed the dentine. The granules of enamel were ground in an agate mortar. Fractions from 0.1 mm to 0.8 mm were taken for analyses. The prepared samples of tooth enamel were degreased by successive washing in acetone, distilled water and alcohol and dried at a room temperature.

We used an EPR-spectrometer type ESP 300E manufactured by "Bruker" with a cylindrical resonator 9601zr330 and operating 3.2 cm wavelength. The minimal detectable dose is 50 mGy, the error depends on the dose value and mass of the enamel analysed. On average, one can accept the error of about 10-20%. Upon that it should be noted that the cumulative external individual doses from natural sources of radioactivity are in the range of 0.1-0.2 Gy for the entire life. The external doses, cumulative as a result of standard medical examinations, are of 0.01 R.

1.5. Assessment of doses with chromosomal aberrations

During the works peripheral blood samples were taken from 50 people living in Sarzhal village. The villagers of Tausugur of Almaty Region were taken as a control group.

A method of peripheral blood lymphocytes culture technique was used. The blood of the examined was sampled from the cubital vein at a rate of 5.0 ml with an addition of heparin. Lymphocytes were cultured in growth medium RPMI-1640 with an addition of 15% calf serum, PHA (Pan-ECO) (0.1 ml per 5 ml of medium) for growth, 0.1 ml of streptomycin, and 0.1 ml of penicillin. The cells were incubated at 37ºC during 48 hours. To accumulate metaphase plates in culture medium 2 hours before the fixation a colchicine was added at a final concentration of 0.1 mg per 1 ml. Chromosome preparations were made by the standard method: after centrifugation for 5 min at 1,200 r/min a 0.56% solution of potassium chloride was added for hypotonic treatment of the cells and incubated in a water bath for 15 minutes at 37ºC. The fixation was performed with a mixture of methanol and glacial acetic acid (3:1). The made cell suspension was transferred to the cold wet glass slides. After drying, the obtained preparation was stained with the 2% Giemsa dye.

In the analysis of metaphase plates a number of cells with aberrations and the number and type of aberrations per 100 analysed metaphases were determined. The obtained data were processed using standard statistical methods.

2. RESULTS AND DISCUSSION

Assessing the impact of artificial radioactive contamination on the population health living in an area of influence of the Semipalatinsk Nuclear Test Site remains a complex methodological challenge; to solve these problems, comprehensive studies were carried out to see the contribution of artificial radionuclides in shaping the cumulative doses to the population living in Sarzhal village.

The examined cohort was represented by persons residing directly during the formation of dose loads in the studied area, and by those moved in later. The main group included 44 people living in the village Sarzhal since 1949 to present. The comparison group had 6 people who moved in or were born in Sarzhal after 1963. The main part of the examined was engaged in agricultural activities, increasing the risk of exposure due to inhalation factor. In order to assess the possible impact of non-radiation factors in the formation of biological effects, further criteria were studied influencing the genetic homeostasis. Of those examined, smokers were 18 people, 8 patients were reported to have oncological diseases in family history, 11 – pregnancy failure and congenital anomalies.

2.1. Contents of artificial radionuclides in urine

Table 4 presents the results of determining the specific activity of radionuclides in urine of the people surveyed.

Table 4.

Specific activity of radionuclides in urine

Donor #	Specific activity of radionuclides, Bq/kg					
	^{40}K	^{241}Am	^{137}Cs	^{3}H*	^{90}Sr	$^{239+240}$Pu
01	60±8	<1	<0.27	<12	<0.1	<0.0012
02	80±8	<0.07	<0.09	<12	<0.1	<0.015
03	100±2	<0.04	<0.05	<12	<0.1	<0.003
04	43.5±5	<0.06	<0.07	<13	<0.1	<0.003
05	120±4	<0.07	<0.09	<13	<0.1	<0.004
06	105±3	<0.05	<0.05	<13	<0.1	<0.006
07	34±3	<0.35	<0.006	<12	<0.1	<0.00231
08	60±6	<0.41	<0.08	<13	<0.1	<0.008
09	70±8	<1.61	<0.27	<12	<0.1	<0.0037
10	52.2±0.4	<0.003	<0.01	<12	<0.1	<0.0028
11	18.2±0.4	<0.009	<0.009	<12	<0.1	<0.00157
12	70±8	<0.38	<0.07	<16	<0.1	<0.0034
13	80±8	<2	<0.33	<12	<0.1	-
14	7.1±0.4	<0.006	<0.01	<12	<0.1	<0.0066
15	36±4	<0.102	<0.02	<12	<0.1	<0.0019
16	42.2±1.1	<0.027	<0.025	<13	<0.1	<0.0078
17	67.7±1.2	<0.007	<0.01	<13	<0.1	<0.00266
18	100±10	<1.7	<0.3	<14	<0.1	<0.0016
19	30±3	<0.21	<0.06	<19	<0.1	<0.0009
20	95±10	<0.7	<0.3	<19	<0.1	<0.00205
21	20±2	<0.2	<0.06	<19	<0.1	<0.00104
22	20.5±0.6	<0.004	<0.006	<19	<0.1	<0.0007
23	72±7	<1.2	<0.27	<18	<0.1	<0.0025
24	80±8	<0.9	<0.15	<19	<0.1	<0.0013
25	41±4	<0.008	<0.024	<18	<0.1	<0.00591
26	24.5±1	<0.007	<0.011	<18	<0.1	-
27	27.6±1.4	<0.009	<0.014	<17	<0.1	<0.0015
28	35±4	<0.35	<0.07	<17	<0.1	<0.0017
29	46±5	<0.43	<0.06	<18	<0.1	<0.00145
30	43.2+-0.9	<0.05	<0.008	<19	<0.1	<0.00215
31	47.4±1	<0.006	<0.014	<19	<0.1	<0.00404
32	62±6	<1.8	<0.33	<18	<0.1	<0.0047
33	55±6	<0.32	<0.06	<18	<0.1	<0.00111
34	8.5±0.4	<0.005	<0.008	<19	<0.1	<0.00419
35	65±7	<0.3	<0.06	<18	<0.1	-
36	30±3	<0.41	<0.07	<18	<0.1	<0.0021
37	40±4	<0.8	<0.23	<18	<0.1	<0.00394
38	76±8	<1.3	<0.23	<17	<0.1	<0.00221
39	88±9	<1.7	<0.32	<13	<0.1	<0.0175
40	15.5±1.1	<0.015	<0.026	<14	<0.1	<0.0298

Donor #	Specific activity of radionuclides, Bq/kg					
	^{40}K	^{241}Am	^{137}Cs	^{3}H*	^{90}Sr	$^{239+240}$Pu
41	42±4	<0.38	<0.07	<13	<0.1	<0.01
42	70±7	<1.8	<0.27	<13	<0.1	<0.006
43	42.6±1.3	<0.025	<0.026	<13	<0.1	<0.009
44	30±3	<0.41	<0.07	<13	<0.1	<0.0133
45	<20	<1.9	<0.66	<13	<0.1	<0.023
46	20±3	<0.13	<0.03	<13	<0.1	<0.003
47	60±6	<1.6	<0.15	<13	<0.1	<0.005
48	35.3±0.6	<0.012	<0.021	<13	<0.1	<0.009
49	7.1±0.4	<0.006	<0.01	<13	<0.1	<0.006
50	8.5±0.4	<0.005	<0.008	<13	<0.1	<0.006

The studies of the radionuclide contents in the urine indicate that in all analysed samples the content of artificial radionuclides is below the detection limit of used techniques and equipment. According to [4], natural specific activity of ^{40}K in the urine is, on average, up to 74 Bq/kg. Thus, the ^{40}K content does not exceed the reference values.

The content of tritium also does not exceed the detection limits of the instrumentation used. Accordingly, during the works we did not record expected excretion of tritium with the urine for as long as the examined people resided in the city of Kurchatov. It was assumed that the urine of Sarzhal residents would contain a certain amount of tritium entering with milk, which is a staple food, and then, when living in a "clean" area (Kurchatov), and to suspend intake of tritium into the body its excretion can be assessed, but this did not happen.

Radionuclides ^{90}Sr and $^{239+240}$Pu were also not detected by the methods used; their contents are below the detection limits of the instrumentation used.

2.2. Calculation of doses based on the study of radionuclides in urine

According to the methodological recommendations in the IAEA and ICRP publications, we performed a conservative assessment of intake for the radionuclides ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am and estimated the dose loads. Since all the data on specific activities of ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am in the urine listed in Table 4 are below the detection limit, for a conservative assessment of the expected dose loads the maximal detection limits were taken for these radionuclides. Effective dose of internal irradiation was calculated for peroral and inhalation pathways of intake of ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am.

When calculating the effective dose of internal exposure from inhalation intake of ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am, particle sizes were taken into account, i.e. MADA (median aerodynamic diameter of activity). In case of inhalation intake, to calculate the internal dose of the population, the IAEA recommends to use MADA equal to 1 micron. When calculating the effective dose of internal exposure from ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am inhalation intake, the absorption coefficients by intestine were taken into account. At inhalation and peroral pathways of intake it is needed to consider the chemical form (type) of incoming compounds with ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am. Since the type of incoming compounds of ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am is not known, the calculation was made for all types of chemical forms of F, M and S of these radionuclides. Given that the assessment of the expected dose load was accepted as the upper bound, we compared the calculation results of doses from inhalation and peroral pathways of intake for types F, M and S of entering compounds of ^{3}H, ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am, and listed the maximal doses.

Table 5 presents the results from the conservative assessment of internal doses based on the studies of radionuclides in urine.

Table 5.

Assessment of internal doses based on the studies of radionuclides in urine

Radionuclide	Type of incoming compounds	Internal dose	
		mSv over 50 years	mSv over a year
^{3}H		<9.2×10^{-1}	<1.8×10^{-2}
^{90}Sr	type S	<1.3×10^{3}	<25
^{137}Cs	type F	<1.5×10^{3}	<31
$^{239+240}$Pu	type S	<3.09×10^{3}	<61.8
^{241}Am	type M	<4.3×10^{4}	<850

Such high values of internal dose limits for ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am are associated with a high detection limit. To better assess the contents of ^{90}Sr, ^{137}Cs, $^{239+240}$Pu, ^{241}Am in the urine, it is required to increase the urine samples taken and exposure time, or switch to another type of analysis, such as determination of $^{239+240}$Pu in urine using the method of accelerative mass spectrometry .

2.3. Calculation of cumulative doses using the results from direct determination of artificial radionuclides in human body

Table 6 shows the results of determining concentrations of ^{137}Cs and ^{241}Am in the examined body using a body counter, as well as the results from calculation of dose loads based on these data.

Table 6.

Results of studies by direct dosimetry (WBC)

##	Specific activity, whole body		Internal dose			
	^{137}Cs	^{241}Am	^{137}Cs	^{241}Am	^{137}Cs	^{241}Am
	Bq/kg	Bq/kg	mSv over a year	mSv over a year	mSv over 50 years	mSv over 50 years
1	<0.27	<1	<6.2×10^{-4}	<18	<3.1×10^{-2}	<918
2	<0.23	<1.01	<5.2×10^{-4}	<19	<2.6×10^{-2}	<971
3	<0.21	<0.84	<4.8×10^{-4}	<19	<2.4×10^{-2}	<954
4	<0.167	<0.69	<3.8×10^{-4}	<19	<1.9×10^{-2}	<954
5	<0.26	<1.05	<5.9×10^{-4}	<19	<2.9×10^{-2}	<936
6	<0.15	<0.58	<3.4×10^{-4}	<18	<1.7×10^{-2}	<883
7	<0.13	<0.53	<2.9×10^{-4}	<13	<1.5×10^{-2}	<653
8	<0.14	<0.57	<3.2×10^{-4}	<13	<1.6×10^{-2}	<653
9	<0.08	<0.34	<1.8×10^{-4}	<13	<9.2×10^{-2}	<653
10	<0.1	<0.43	<2.3×10^{-4}	<13	<1.1×10^{-2}	<653

##	Specific activity, whole body		Internal dose			
	^{137}Cs	^{241}Am	^{137}Cs	^{241}Am	^{137}Cs	^{241}Am
	Bq/kg	Bq/kg	mSv over a year	mSv over a year	mSv over 50 years	mSv over 50 years
11	<0.17	<0.68	$<3.9\times10^{-4}$	<13	$<1.9\times10^{-2}$	<653
12	<0.12	<0.48	$<2.7\times10^{-4}$	<13	$<1.3\times10^{-2}$	<653
13	<0.17	<0.9	$<3.9\times10^{-4}$	<18	$<1.9\times10^{-2}$	<901
14	<0.18	<0.9	$<4.1\times10^{-4}$	<25	$<2.0\times10^{-2}$	<1250
15	<0.10	<0.5	$<2.3\times10^{-4}$	<16	$<1.1\times10^{-2}$	<795
16	<0.12	<0.6	$<2.7\times10^{-4}$	<17	$<1.3\times10^{-2}$	<830
17	<0.20	<0.8	$<4.3\times10^{-4}$	17	$<2.1\times10^{-2}$	<865
18	<0.18	<0.9	$<4.1\times10^{-4}$	<18	$<2.0\times10^{-2}$	<883
19	<0.17	<0.6	$<3.9\times10^{-4}$	<12	$<1.9\times10^{-2}$	<600
20	<0.13	<0.5	$<2.9\times10^{-4}$	<13	$<1.5\times10^{-2}$	<636
21	<0.11	<0.4	$<2.5\times10^{-4}$	<11	$<1.2\times10^{-2}$	<565
22	<0.11	<0.4	$<2.5\times10^{-4}$	<12	$<1.2\times10^{-2}$	<600
23	<0.17	<0.7	$<3.9\times10^{-4}$	<13	$<1.9\times10^{-2}$	<653
24	<0.12	<0.5	$<2.7\times10^{-4}$	<13	$<1.3\times10^{-2}$	<671
25	<0.14	<0.6	$<3.2\times10^{-4}$	<14	$<1.6\times10^{-2}$	<706
26	<0.18	<0.7	$<4.1\times10^{-4}$	<13	$<2.0\times10^{-2}$	<653
27	<0.14	<0.5	$<3.2\times10^{-4}$	<12	$<1.6\times10^{-2}$	<600
28	<0.17	<0.7	$<3.9\times10^{-4}$	<14	$<1.9\times10^{-2}$	<689
29	<0.16	<0.7	$<3.6\times10^{-4}$	<14	$<1.8\times10^{-2}$	<689
30	<0.14	<0.6	$<3.2\times10^{-4}$	<17	$<1.6\times10^{-2}$	<848
31	<0.12	<0.5	$<2.7\times10^{-4}$	<17	$<1.3\times10^{-2}$	<830
32	<0.11	<0.5	$<2.5\times10^{-4}$	<18	$<1.2\times10^{-2}$	<901
33	<0.11	<0.4	$<2.5\times10^{-4}$	<12	$<1.2\times10^{-2}$	<618
34	<0.09	<0.3	$<2.0\times10^{-4}$	<11	$<1.0\times10^{-2}$	<530
35	<0.12	<0.5	$<2.7\times10^{-4}$	<14	$<1.3\times10^{-2}$	<689
36	<0.12	<0.5	$<2.7\times10^{-4}$	<13	$<1.3\times10^{-2}$	<671
37	<0.14	<0.6	$<3.2\times10^{-4}$	<14	$<1.6\times10^{-2}$	<689
38	<0.10	<0.4	$<2.3\times10^{-4}$	<13	$<1.1\times10^{-2}$	<671
39	<0.16	<0.7	$<3.6\times10^{-4}$	<14	$<1.8\times10^{-2}$	<689
40	<0.20	<0.8	$<4.6\times10^{-4}$	<17	$<2.3\times10^{-2}$	<848
41	<0.3	<1.2	$<6.9\times10^{-4}$	<19	$<3.4\times10^{-2}$	<971
42	<0.2	<0.9	$<4.6\times10^{-4}$	<19	$<2.3\times10^{-2}$	<954
43	<0.14	<0.5	$<3.2\times10^{-4}$	<12	$<1.6\times10^{-2}$	<618
44	<0.11	<0.4	$<2.5\times10^{-4}$	<12	$<1.2\times10^{-2}$	<600
45	<0.18	<0.7	$<4.1\times10^{-4}$	<13	$<2.0\times10^{-2}$	<671
46	<0.15	<0.6	$<3.4\times10^{-4}$	<14	$<1.7\times10^{-2}$	<706
47	<0.13	<0.5	$<2.9\times10^{-4}$	<14	$<1.5\times10^{-2}$	<706
48	<0.12	<0.5	$<2.7\times10^{-4}$	<13	$<1.3\times10^{-2}$	<671
49	<0.13	<0.5	$<2.9\times10^{-4}$	<13	$<1.5\times10^{-2}$	<636
50	<0.11	<0.4	$<2.5\times10^{-4}$	<12	$<1.2\times10^{-2}$	<583

Since all the data on specific activities of ^{137}Cs and ^{241}Am in human body are below the detection limit, the maximal limits of detection for these radionuclides were taken calculating the expected dose loads. According to the results of the conservative assessment, the expected effective dose of internal radiation from ^{137}Cs will not exceed 3.45×10^{-2} over 50 years, from ^{241}Am - 1.25×10^{3} mSv over 50 years. Consequently, the expected effective dose of internal radiation does not exceed 6.9×10^{-4} mSv per year from ^{137}Cs, from ^{241}Am 25 - mSv per year.

The achieved detection limits of specific activity of ^{137}Cs are enough to measure the dose. However, the limits of internal doses from ^{241}Am are high, which is associated with a high detection limit. To better assess contents of ^{241}Am in human body it is required to extend the exposure time, make changes in the instrumental base, improve background characteristics of the protective chamber.

The calculation of cumulative doses based on the studies of radionuclides in urine and the results from direct determination of artificial radionuclides in human body leads to the conclusion that it is better to use data from WBC to assess the dose loads from ^{137}Cs and ^{241}Am. When comparing the assessment results of ^{137}Cs and ^{241}Am dose loads based on determination of incorporated radionuclides by direct and indirect methods, a conclusion comes that the sensitivity of such assessment based on the direct method is higher than that of the indirect method.

Calculation of cumulative external dose of tooth enamel using EPR method

Table 7 shows the results of determining the dose loads to the population of Sarzhal village using the method of EPR dosimetry.

Table 7.

Reconstruction of dose loads to the Sarzhal village population using EPR dosimetry

##	Sample #	Gender	Date of birth	Place of birth	Place of residence	Tooth position	Dose (Gy)
1	2	M	1994	Sarzhal	Sarzhal	r.*u.*4	0.03
2	4	M	1944	Sarzhal	Sarzhal	r.l.*6 r.u.4	0.27 0.35
3	5	M	1960	Sarzhal	Sarzhal	r.l.6	0.06
4	17	M	1938	Sarzhal	Sarzhal	r.u.4	0.28
5	18	M	1949	Sarzhal	Sarzhal	lf.*u.6	0.11
6	22	M	1963	Sarzhal	Sarzhal	r.u.6	0.12
7	23	M	1962	Sarzhal	Sarzhal	r.l.5	0.16
8	26	M	1959	Sarzhal	Sarzhal	lf.u.5	0.08
9	27	M	1972	Sarzhal	Sarzhal	r.u.6	0.11
10	33	M	1957	Sarzhal	Sarzhal	lf.l.4	0.16
r.*, lf.*, u.*, l.* - right, left, upper, lower							

According to Table 6, we can note that there are isolated cases of elevated doses, which could be obtained due to radioactive fallouts in the area, and also due to other reasons such as unauthorized access to the contaminated areas of the test site with high background radiation.

2.5. Calculation of cumulative dose based on chromosomal aberrations

Table 8 presents the results from the study of chromosome aberrations frequency in Sarzhal villagers.

Table 8.

Frequency of chromosomal aberrations in residents of Sarzhal village

#	Cells with aberrations (%)	Total aberrations (%)	Chromosomal type (%)				Chromo-somal type (%)
			Total	Dicentric+ ring	Transloca-tion	Ruptures, fragments, exchanges	
1	2	3	1			1	2
2	3.5	5	3	1		2	2
3	4	4	3			3	1
4	9	9	2			2	7
5	1.7	1.7	0				1.7
6	1	1	1			1	0
7	8.6	8.6	7.1			7.1	1.5
8	5	5	0				5
9	5	5.1	4	1	1	2	1.1
10	3.5	3.5	2.5			2.5	1
11	3.5	3.5	2			2	1.5
12	4	4	1			1	3
13	5	5	2			2	3
14	1	2	1			1	1
15	1	1	0				1
16	2	2	0				2
17	1	1	0				1
18	2	2	2		1	1	0
19	3	3	1			1	2
20	1	1	1		1		0
21	1	1	1			1	0
22	1	1	1	1			0
23	3	3	2			2	1
24	1	1	1			1	0
25	2	2	1			1	1
26	1	1	1	1			0
27	0	0	0				0
28	2	2	1	1			1
29	1	1	0				1
30	2	2	0				2
31	3	3	3			3	0
32	3	3	1			1	2

#	Cells with aberrations (%)	Total aberrations (%)	Chromosomal type (%)				Chromo-somal type (%)
			Total	Dicentric+ ring	Transloca-tion	Ruptures, fragments, exchanges	
33	3	3	1			1	2
34	2	2	2	1		1	0
35	3	3	0				3
36	1	1	0				1
37	0	0	0				0
38	2	3	0				3
39	3	3	0				3
40	1	2	0				2
41	3	3	1			1	2
42	3	3	3			3	0
43	0	0	0				0
44	7.5	9.5	6			6	3.5
45	4	4	1			1	3
46	5	7	5		1	4	2
47	6	6	4		1	3	2
48	2	2	0				2
49	4	4	2			2	2
50	3	3	1			1	2
51	5	6	5			5	1
52	2	2	1		1		1
	2.81±0.16	3.02±0.17	1.42±0.12	0.115±0.03	0.115±0.03	1.2±0.12	1.60±0.12
K	0.87 ± 0.1	0.87 ± 0.1	0.19 ± 0.05	0	0	0.19 ± 0.05	0.68 ± 0.09
	K – control						

The frequency of chromosomal aberrations in the residents of Sarzhal comprised 3.02±0.17%, which is almost 3.5 times higher than that in the residents of Tausugur village of Almaty region - 0.87±0.1%. This village was selected as a reference because, firstly, it is in ecologically pure mountain region, and secondly, for reasons of comparable results accuracy – the rural population to be compared with rural, urban to be compared with urban.

The comparative analysis of the aberrations types in the control group (Tausugur village) (Figure 1) showed that at the less radical increase in the aberration frequency of chromatid type (2.35 times), there are more than 7-fold excess of chromosome type aberrations, which indicates the predominant influence of genotoxicants of radiation nature.

Analysis of the cytogenetic disturbances spectrum in the examined persons showed that there were aberrations both of chromosomal type - 1.42±0.32 %, and chromatid type - 1.6±0.36%. Such a pattern of structural chromosomal disorders may be related to both radiation and chemical genotoxicants. Aberrations of chromosomal type were presented with double ruptures and fragments, dicentrics and translocations, of the second - single ruptures, fragments and inter-chromatid exchanges.

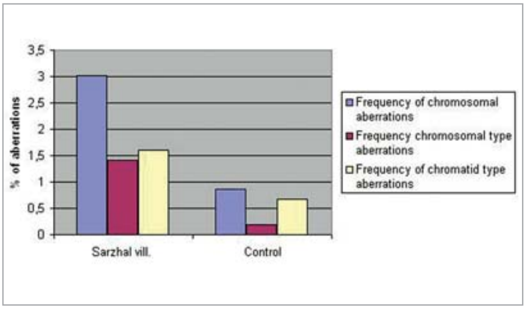

Figure 1. Distribution of chromosomal aberrations structure in the examined persons by aberrations types

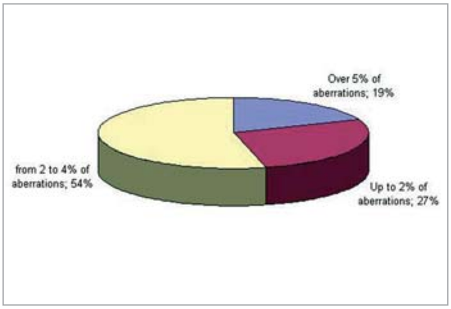

Figure 2. Frequency of chromosomal aberrations in the examined persons

When systematizing the frequency of chromosomal aberrations in peripheral blood lymphocytes, the surveyed contingent was divided into three groups: those with chromosomal aberrations in peripheral blood lymphocytes up to 2%, from 2 to 5% and 5% and above. The first group (1) includes a cohort of people with spontaneous level, the second (2) – high and the third ("h") - a high level of chromosomal aberrations (Figure 2). As shown on the figure, only in 1/4 of the examined (27%), the frequency of disorders did not exceed the general population spontaneous level for Kazakhstan, in more than half (54%) it was higher and in 1/5 (19%) – high. Total, in 38 surveyed people (73%), the frequency of chromosomal aberrations exceeded the spontaneous level for 2-5 times.

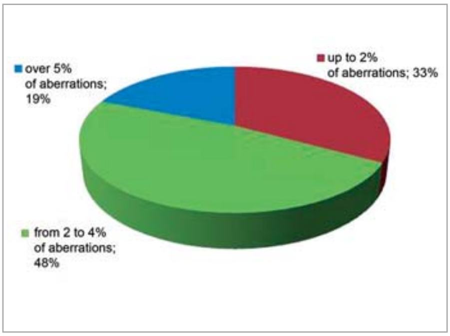

Figure 3. Frequency distribution of chromosome types in the examined people from Sarzhal

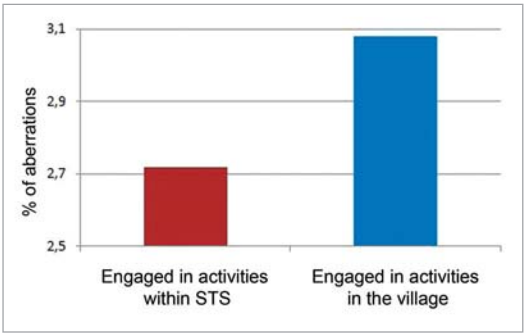

Figure 4. Analysis of chromosomal aberrations in individuals, depending on the type of employment

Of all the types of chromosomal aberrations, for diagnosis of radiation injuries most commonly a count of dicentrics, acentric fragments and centric rings, i.e. aberrations of chromosomal type, is used. In this regard, the aberrations frequency distribution of chromosomal type (Figure 3) was analysed. Comparison of the diagrams in Figures 1 and 2 shows that there are no fundamental or statistically significant differences between them. This is another evidence that the increase in cytogenetic disorders is due to an increase in the number of dicrotic chromosomal rearrangements (dicentrics, rings, translocations, double ruptures and fragments) which are markers of radiation exposure; however, since the frequency of chromatid type aberrations is still raised, in the further analysis we relied on the overall frequency of cytogenetic disorders.

As it was shown above, there is high variability in the frequency of chromosomal aberrations in the studied group. Because they are exposed to radiation, the dependence of this rate on the timing of human habitation in the village (until 1962, during and after the surface nuclear tests) was analyzed, as well as on the type of employment - related or not with a visit to STS (Figures 4 and 5, respectively).

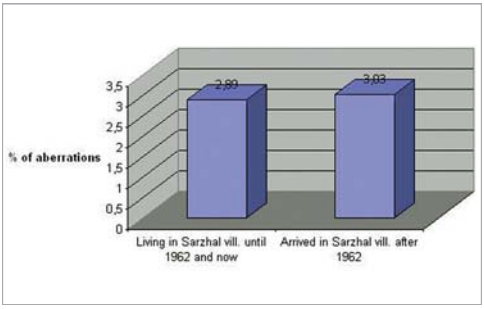

Figure 5. Frequency of chromosomal abnormalities, depending on duration of residence in Sarzhal

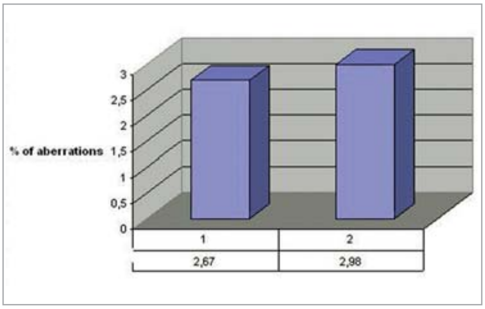

Figure 6. Frequency of chromosomal aberrations in individuals whose blood relatives are ill or have died from oncological diseases

As seen from the diagrams, there is no reliable difference between the compared figures, i.e. the individuals exposed to radiation genotoxicants for a longer time show no increase in the level of cytogenetic disturbances; on the contrary it is even more reduced.

Quantitative assessment of cytogenetic damage in mammalian and human cells at ionizing radiation is extremely important because it can serve as a criterion of risk of low radiation doses; as it is well known, genetic alterations play critical role in radiation mutagenesis and carcinogenesis.

In this regard, we analyzed frequency of chromosomal aberrations in individuals whose blood relatives are ill or have died from oncological diseases (Figure 6) and in individuals with a history of unprompted miscarriage, stillbirths and children with disabilities (Figure 7). As seen from the diagrams, in this study, we failed to reveal the frequency of cytogenetic damage with carcinogenic and reproductive risk, despite the elevated levels of these health parameters among the population. This is probably due to either a statistically small group of the examined or, that is more likely, the genetic disorders that cause increased risk of these criteria should be sought on a more subtle level of the genetic make-up, rather than the rough – the chromosome.

There is some evidence that smoking may aggravate the genotoxic effects of different factors. The smokers and those chewing tobacco have elevated levels of SCE and single fragment in lymphocytes [23-24]. The results obtained by the authors suggest a synergistic effect of smoking factor and the whole complex of factors in the process of induced mutagenesis. Based on this, we analyzed frequency of chromosomal aberrations in smokers and nonsmokers of Sarzhal residents (Figure 8). As seen from the diagram, although people who smoke have somewhat higher frequencies of chromosomal aberrations than nonsmokers do, but these differences are not statistically reliable.

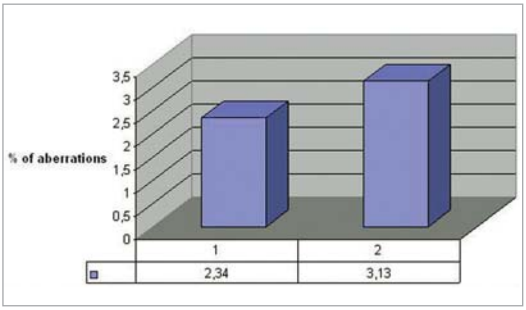

Figure 7. Frequency of chromosomal aberrations in individuals with miscarriages, stillbirths, children with disabilities in the past history

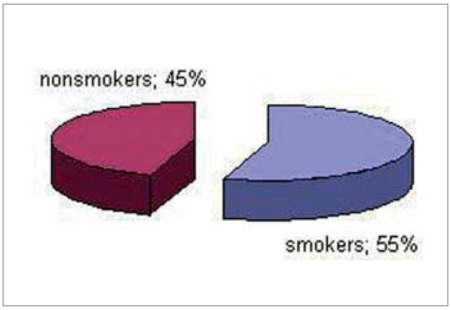

Figure 8. Frequency ratio of chromosomal aberrations in smoker and nonsmoker residents of Sarzhal vil.

The studies found increased frequency of chromosomal abnormalities in the main group – 3.02±0.17% compared to control – 0.87 ± 0.1%. The high variability in the frequency of chromosomal aberrations – from 0 to 9.5% in the examined people and lack of relation with the epidemiological data indicates the population heterogeneity by radiosensitivity criterion. The results presented here also show the incompetence of risk assessment of low doses by linear extrapolation from the effects of high doses, because biological response to ionizing radiation varies with the dose due to induction of repair processes, which is "launched" after a certain threshold of cell damage.

In different individuals from the cohort studied, the frequency of chromosomal aberrations varied over a wide range – from 0 to 13%; at that more than 45% of the surveyed people had 3 and more percent of cells with cytogenetic disorders.

The spectrum of chromosomal aberrations had both chromosomal aberrations – 1.39±0.32% and chromatid types – 1.89±0.36%. Chromosomal aberrations are represented by double ruptures and fragments, dicentrics and translocations, chromatid aberrations – single ruptures, fragments and inter-chromatid exchanges.

CALCULATION OF CUMULATIVE DOSES

As it is known, the markers of radiation damage are aberration of the chromosomal type, and chemical – the chromatid type. Therefore, at a less radical increase in the frequency of chromatid type aberrations (2.8 times), there is more than 7-fold excess of chromosomal aberration type.

Given that the dicentric + translocation in some formulas do not appear as the dicentrics and rings refer to unstable aberrations and translocation – to the stable one. We attempted to assess the dose-effect at routine analysis based on the number of unstable aberrations – dicentrics and rings. As it can be seen from Table 4, these figures were revealed only in 6 persons surveyed. On this basis, the approximate value of the cumulative radiation dose can be determined for this group. Below is the calculation of doses using the accepted methods for calculation:

1) According to the original formula by Lloyd:

$$D=y/0.022$$

D – dose absorbed (equivalent) (Sv)
У – frequency of dicentrics
0.022 – standard coefficient.

Because in all individuals the revealed frequency of dicentrics + ring is similar, then the calculation and value are the same as well.

$$D=0.01/0.022=0.45 \text{ Sv.}$$

2) If one calculates employing the formula recommended by the IAEA for the fractionated irradiation:

$$Y=\alpha D+\beta D^2,$$

then we get **0.23 Sv**
D – dose absorbed (equivalent) (Sv)
У – frequency of dicentrics
α – 0.03 (coefficient)
β – 0.06 (coefficient).

3) When using a calibration curve dose-effect a value 0.22 - 0.25 Gy was obtained. Equivalent dose – **0.22-0.25 Sv.**

CONCLUSION

No such radionuclides as ^{137}Cs, ^{241}Am, ^{90}Sr, $^{239+240}$Pu and ^{3}H were found in the bodies of any of the people surveyed; at that, the achieved limits of the instrumentation sensitivity for determination of ^{137}Cs, ^{90}Sr and ^{3}H are sufficient to assess the cumulative dose for the population. However, to assess the cumulative dose from such radionuclides as $^{239+240}$Pu and ^{241}Am, it is required to increase the sensitivity of the methods for their determination.

Assessment of cumulative external radiation dose by EPR of tooth enamel indicates the population heterogeneity of Sarzhal villagers and the potential for additional exposure from other sources not related to artificial contamination in the village lands.

Assessment of cumulative effective doses of internal irradiation for Sarzhal villagers based on chromosomal aberrations showed no relation between the level of chromosomal aberrations and time of residence in the radioactively contaminated area. For objective assessment of cumulative effective dose on the population living in the zone of influence of the Semipalatinsk test site, it is needed to study the contribution of natural radionuclides into the formation of total cumulative effective dose.

REFERENCES

1. V.A. Logachev. Soviet nuclear tests. Semipalatinsk Nuclear Test Site: ensuring general and radiation safety of nuclear testing. [in Russian]
   Логачев В.А. Ядерные испытания СССР. Семипалатинский полигон: обеспечение общей и радиационной безопасности ядерных испытаний / В.А. Логачев и [др.]. - М.: ФУ "Медбиоэкстрем", 1997.
2. Activity of radionuclides in bulk samples. Methods for measurement on gamma – spectrometer. [in Russian]
   Активность радионуклидов в объемных образцах. Методика выполнения измерений на гамма - спектрометре: МИ 2143-91. - Введ. 1998-06-02. - Рег. № 5.06.001.98. – М.: НПО ВНИИФТРИ, 1991. - 18 с.
3. Water quality – Determination of tritium activity corresponding to a given concentration - Liquid scintillation counting method. The international standard ISO 9698:1989. [in Russian]
   Тритий. Качество воды – определение активности трития, соответствующей данной концентрации - жидкостной метод сцинтилляционного счета. Учетная регистрация в Республике Казахстан № 116/149 от 07.03.2000: ISO 9698 РК, 1989.
4. Methods for determining the content of artificial radionuclides plutonium-239. 240. strontium-90 and cesium-137 in natural waters by concentration method: registration No. 0307/3 of 04.05.2001. - Kurchatov: INP NNC RK, 2001. [in Russian]
   Методика определения содержания искусственных радионуклидов плутония-239.240. стронция-90 и цезия-137 в природных водах методом концентрирования: регистрационный №0307/3 от 5.04.2001. – Курчатов : ИЯФ НЯЦ РК, 2001.
5. International Commission on Radiological Protection, Individual Monitoring for Internal Exposure of Workers (Revision of ICRP Publication No. 54) Publication No. 78. Ann. ICRP 27 3–4. Elsevier Science Ltd. – Oxford, 1997.
6. Assessment of doses to the public from ingested radionuclides. Safety Reports series No. 14. International Atomic Energy Agency. – Vienna: International Atomic Energy Agency, 1999.
7. Assessment of occupational exposure due to intakes of radionuclides. Safety Guide. № RS-G-1.2. - Vienna: International Atomic Energy Agency, 1999. [in Russian]
   Оценка профессионального облучения вследствие поступления радионуклидов. Руководство по безопасности. №RS-G-1.2. - Вена: Международное агентство по атомной энергии, 1999.
8. Methods for Assessing Occupational Radiation Doses Due to Intake of Radionuclides. Safety Report series No.37. - Vienna: International Atomic Energy Agency, 2004.
9. Indirect Methods for Assessing Radionuclides Causing Occupational Exposure. Safety Report series No.18.- Vienna: International Atomic Energy Agency, 2000.

10. Брянцева Н.В. Расчет доз от изотопов плутония по результатам исследования его содержания в моче для населения, проживающего в зоне влияния СИП / Н.В. Брянцева, А.В. Топорова, А.А. Жадыранова, С.Н. Лукашенко// Актуальные вопросы радиоэкологии Казахстана [Сборник трудов Института радиационной безопасности и экологии за 2007 – 2009гг.]. – Вып. 2. – Павлодар: Дом печати, 2010. – С. 463-474. : ил. - Библиогр.: с. 54. - ISBN 978-601-7112-32-5.
    N.V. Bryantseva. Calculation of doses from plutonium isotopes based on the study of its concentration in urine of the population in the STS impact zone / N.V. Bryantseva, A.V. Toporova, A.A. Zhadyranova, S.N. Lukashenko // // Topical Issues in Radioecology of Kazakhstan [Proceedings of the Institute of Radiation Safety and Ecology for 2007-2009] [in Russian]
11. Ikeya M. New applications of Electron Spin Resonance - Dating, Dosimetry and Microscopy / M. Ikeya // Word Scientific. – Singapore, 1993. - 500 pages.
12. Medical consequences of the Chernobyl accident: Research Report (WHO). - Geneva, 1996. [in Russian]
    Медицинские последствия Чернобыльской аварии: научный отчет (АЙФЕК, ВОЗ). - Женева, 1996. - 559 с.
13. Romanyukha A. A. Pilot study of the population of the Ural region by EPR tooth dosimetry // A.A. Romanyukha, M.O. Degteva, V.P. Kozheurov [et al.]. // Radiat. Emviron.Biophys. -1996. – V. 35. - P. 305-310.
14. Pivovarov S. Exposure subpopulations and peculiarities of individual dose distribution among inhabitants of the Semipalatinsk region / S. Pivovarov, A. Rukhin, T. Seredavina, N. Sushkova, P. Hill, L. Peterson // Radiat. Measurements. – 2007. – V. 42. - P. 1033 – 1036.
15. GOST 22.3.04-96 Dosimetric monitoring of the population. Method for determination of absorbed doses of external gamma radiation based on the electron paramagnetic resonance spectra of tooth enamel - Moscow: Publishing House of Standards, 1996. [in Russian]
    ГОСТ Р 22.3.04-96 Контроль населения дозиметрический. Метод определения поглощенных доз внешнего гамма-излучения по спектрам электронного парамагнитного резонанса зубной эмали. - Введ.15.06.1996. принят в РК в 2003г. – М.: Изд-во стандартов, 1996.
16. IAEA-TECDOC-1331. Use of Electron Paramagnetic Resonance Dosimetry with tooth enamel for retrospective dose assessment. – Vienna: IAEA, 2002 (December).
17. Wieser A. The second international intercomparison on EPR tooth dosimetry / A. Wieser, S. Pivovarov [et al.]. (in total 28 authors) // Journ. "Radiation Measurements". – 2000. – V. 32. - P. 549-557.
18. Wieser A. The 3rd International Intercomparison on EPR tooth Dosimetry: Part I, General analysis / A.Wieser, S. Pivovarov [et al.]. (26 authors) //Appl. Rad. Isot. – 2005. – V.62. - № 2. (Febr.). – P. 163-173.
19. Wieser A. The 3 rd International Intercomparison on EPR Tooth Dosimetry / A. Wieser, S. Pivovarov et al. (23 authors) // Final Analysis. Proceedings of 14th

Intern. Confer. on Solid State Dosimetry New Haven, CT (USA). - USA, 2004. - Part II. – P. 21.

20. Wieser A. The 3rd International Intercomparison on EPR Tooth Dosimetry / A. Wieser, R. Debuyst, P. Fattibene, A. Meghzifene, S. Onori, S. Pivovarov [et al.]. //Proceedings the 6th International Symposium on ESR Dosimetry and Applications. October 12-16. 2003. -San Paulo, Brazil, 2003. - P. 1-24.
21. Fattibene P. The 4th International Comparison of EPR Dosimetry with Tooth Enamel // A.Wieser, E.Adolfsson, L.A.Benevides, M.Brai, F.Callens, V.Chumak, B.Cieselsky, S.Della Monaca, K.Emerich, H.Gustafsson, Y.Hirai, M.Hoshi, A.Israelsson, A.Ivannikov, D.Ivanov, J.Kaminska, Wu Ke, E.Lund, M.Marrale, N.Nakamura, S.Pivovarov, R.A.Reyes, A.A.Romanyukha, A.Rukhin, S.Sholom, V.Skvortzov, V.Stepanenko, H.Swartz, M.A.Tarpan, S.Toyoda, F.Trompier, B.Williams, K.Zhumadilov // Radiat. Measurements, Report on the results. - 2010.- Part 1. (in print.).
22. M.M. Golutvina. Control of intake of radioactive substances into human body and their content / M.M. Golutvina, Yu. V. Abramov. -M. Energoatomizdat, 1989. [in Russian]
    Голутвина М.М. Контроль за поступлением радиоактивных веществ в организм человека и их содержанием / М.М. Голутвина, Ю.В. Абрамов. –М.: Энергоатомиздат, 1989.
23. N.V. Litvyakov. Analysis of the genetic effects of low-level exposure / N.V. Litvyakov, E.O. Vasilyeva, N.V. Mamonova // Health and environmental effects of ionizing radiation. - Tomsk, 2010. [in Russian]
    Литвяков Н.В. Анализ генетических эффектов низкоинтенсивного облучения / Н.В. Литвяков, Е.О. Васильева, Н.В. Мамонова //Медицинские и экологические эффекты ионизирующего излучения. – Томск, 2010.
24. V.E. Balakin. The effect of age stabilization of the genome at low doses of ionizing radiation / V.E. Balakin, S. I. Zaichkina, O.M. Rozanova // Health and environmental effects of ionizing radiation. - Tomsk, 2010. [in Russian]
    Балакин В.Е. Эффект возрастной стабилизации генома при действии малых доз ионизирующего излучения /В.Е. Балакин, С.И. Заичкина, О.М. Розанова //Медицинские и экологические эффекты ионизирующего излучения. – Томск, 2010.
25. Statistical analysis of results from WBC – measurements to assess the internal dose, of villagers in the remote period after the Chernobyl accident / N.G. Vlasova, D. N. Drozdov, L.A. Chunikhin // Radiation biology. Radioecology. - 2009. - Volume 49. - № 4. [in Russian]
    Власова Н.Г. Статистический анализ результатов СИЧ – измерений для оценки дозы внутреннего облучения сельских жителей в отдаленный период после аварии на ЧАЭС / Н.Г.Власова, Д.Н.Дроздов, Л.А.Чунихин // Радиационная биология. Радиоэкология. - 2009. - Том 49. - № 4. -С.397 – 406. N.G. Vlasova.
26. M. I. Balonov. Radiation monitoring of exposure to the population from the territories contaminated after Chernobyl accident / M.I. Balonov, A.N. Barkovsky, G.

Ya. Bruk, V. Yu. Golikov, V. N. Shutov // Guidelines for radiation safety. - Moscow: Russian Agency for Health and Consumer Rights, 2007. [in Russian]
Балонов М. И. Радиационный мониторинг доз облучения населения территорий, подвергшихся радиоактивному загрязнению вследсвтие аварии на Чернобыльской АЭС / М.И. Балонов, А.Н. Барковский, Г.Я. Брук, В.Ю. Голиков, В.Н. Шутов // Методические рекомендации по обеспечению радиационной безопасности. - Москва : Роспотребнадзор, 2007. – С. 54-56.

СЕМЕЙ ЯДРОЛЫҚ СЫНАҚ ПОЛИГОНЫНЫҢ ӘСЕР ЕТУШІ АЙМАҒЫНДА ТҰРАТЫН ТҰРҒЫНДАР ДОЗАСЫН ҚАЙТА ҚҰРУ МӘСЕЛЕСІНЕ

Битенова М.М.[1.] Брянцева Н.В.[1.] Лукашенко С.Н.[1.] Галич Б.В.[1.] Жадыранова А.А.[1.] Каширский В.В.[1.] Мещерякова А.В.[1.] Пивоваров С.П.[2.] Рухин А.Б.[2.] Середавина Т.А.[2.] Чередниченко О.Г.[3.] Губицкая Е.Г.[3.] Байгушикова Г.М.[3]

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Мақалада Семей ядролық сынақ полигонындағы ядолық қару сынақтары салдарынан сәулеленуге ұшыраған тұрғындар дозаларын бағалау бойынша жұмыс нәтижелері берілген. Үлгі ретінде ядролық жарылыс шөгінділері түсуінің кеңістігінде орналасқан, тұрғындары еңбек қызметі процесінде полигон аумағына баратын Sarzhal елді мекені алынды. Жанама әдістерді (несептегі радионуклидтер құрамын анықтау), адам сәулеленуінің есептегішін қолдана отырып тікелей зерттеулер, сондай-ақ ЭПР әдісімен тістер эмаліндегі сыртқы жинақталған дозаны бағалау және хромосомалық аберрациялардың санын анықтау зерттеулері жүргізілді.

ЭПР дозиметрия әдісімен тістер эмалі бойынша жинақталған сыртқы дозаны бағалау жеке тұлғалардың басқа иондық сәулелену көздері есебінен қосымша сәулеленуінің мүмкіндігі мен популяцияның біртексіздігі туралы растайды. Хромосомалық аберрацияларды зерттеу әдісі арқылы жинақталған дозаны бағалау Sarzhal тұрғындарының популяциясына радиациялық әсердің маркерін табудың бақылаумен салыстырғандағы жоғары деңгейі туралы растайды, бұл кезде хромосомалық аберрациялардың табылу жиілігі мен аталған аумақта тұру ұзақтығы арасында байланыс анықталған жоқ.

Алыстағы уақыт кезеңін, елді мекен аумағындағы радиациялық ахуал туралы жеткілікті ақпараттың жоқтығын, тұрғындардың жеке сіңірілген дозаларын ескере отырып, радионуклидтердің ішкі құрамын табу әдісінің сезімталдығын жоғарылату, сондай-ақ радиациялық әсер етуші тұрақты биологиялық маркерлерді анықтау талап етіледі.

Түйін сөздер: дозаларды ретроспективті бағалау, Семей полигоны, АСЕ, жасанды радионуклидтер, цезий-137. америций-241. плутоний изотоптары, тритий, ЭПР-дозиметрия.

К ВОПРОСУ РЕКОНСТРУКЦИИ ДОЗ НАСЕЛЕНИЯ, ПРОЖИВАЮЩЕГО В ЗОНЕ ВЛИЯНИЯ СЕМИПАЛАТИНСКОГО ЯДЕРНОГО ИСПЫТАТЕЛЬНОГО ПОЛИГОНА

Битенова М.М.[1.] Брянцева Н.В.[1.] Лукашенко С.Н.[1.] Галич Б.В. [1.]Жадыранова А.А.[1]Каширский В.В.[1.], Мещерякова А.В., [1.] Пивоваров С.П.[2]Рухин А.Б.[2]Середавина Т.А., [2] Чередниченко О.Г.[3], Губицкая Е.Г.[3.] Байгушикова Г.М.[3]

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В статье даны результаты работ по оценке доз населения, подвергавшегося облучению вследствие испытаний ядерного оружия на Семипалатинском ядерном испытательном полигоне. В качестве модели взят населенный пункт Sarzhal, расположенный в ареале выпадения осадков ядерного взрыва, население которого в процессе трудовой деятельности посещает территорию полигона. Проведены исследования содержания радионуклидов в организме обследуемых лиц с применением косвенных методов (определение содержания радионуклидов в моче), прямые исследования с использованием счетчика излучения человека, а также оценка внешней накопленной дозы в эмали зубов методом ЭПР и определение числа хромосомных аберраций.

Оценка накопленной внешней дозы по эмали зубов методом ЭПР дозиметрии свидетельствует о неоднородности популяции и вероятности дополнительного облучения отдельных лиц за счет иных источников ионизирующего излучения. Оценка накопленной дозы методом исследования хромосомных аберраций свидетельствует о повышенном, в сравнении с контролем, уровне обнаружения маркеров радиационного воздействии в популяции жителей Sarzhala, при этом не выявлена связь между частотой обнаружения хромосомных аберраций и продолжительностью проживания на данной территории.

Учитывая отдаленный временной период, отсутствие достаточной информации о радиационной обстановке на территории населенного пункта, индивидуальных поглощенных дозах населением, требуется повысить чувствительность методов обнаружения внутреннего содержания радионуклидов, а также определение стойких биологических маркеров радиационного воздействия.

Ключевые слова: ретроспективная оценка доз, Семипалатинский полигон, СИЧ, искусственные радионуклиды, цезий-137. америций-241. изотопы плутония, тритий, ЭПР-дозиметрия.

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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 under the Director General of the International Atomic Energy Agency. He is a co-author in over 110 scientific publications.

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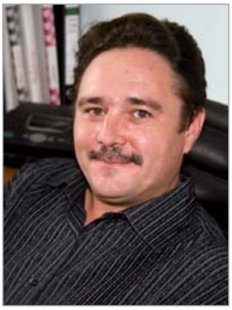

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